# THE JOURNAL
OF THE
# ROYAL AERONAUTICAL SOCIETY

(FOUNDED 1897 in succession to the ANNUAL REPORTS)

Edited for the Council by J. LAURENCE PRITCHARD, Fellow

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## NOTICES

### *Index to the Journal*

Inserted loosely in this issue of the Journal will be found the title page and index to the 1926 volume. Members may have their copies bound in the standard cover on payment of 4s. 6d. to the Society. The copies should be forwarded direct to the Lewes Press, Limited, High Street, Lewes, with the address to which they are to be returned; 5s. 6d. is charged for binding earlier volumes.

### *Paris Aero Show*

Members of the Society visiting the Paris Aero Show will find copies of various publications of the Society on exhibition at the stand of M. Branger, in the Section de Tourisme. A representative of the Society will be in touch with M. Branger. Arrangements have been made for a letter of introduction to be given to any member of the Society, who shows his membership card to M. Branger, or the Society's representative, to enable him to visit certain French aircraft works if he wishes.

### *Appointments Vacant*

Messrs. the Blackburn Aeroplane and Motor Company have written to say that they are considering applications for positions as Senior Draughtsmen. Members of the Society should apply direct to the firm at Brough, and also notify the Secretary of the Society that they have applied. Attention is drawn to the fact that the Society has an Appointments Board, full particulars of which may be had on application.

### *Elections*

The following members were elected at a meeting of Council held on November 2nd, 1926:—

*Associate Fellows.*—Flt. Lt. H. P.-G. Leigh, Mr. A. S. Keep and Major T. P. Searight.

*Students.*—Mr. H. Parr, Mr. E. C. Reeve, Mr. A. G. Store, Mr. O. J. Tapper and Mr. P. G. Thomson.

*Members*—Mr. J. F. Fyfe-Jamieson and Eng. Lt. Cdr. T. Nakamura.

### *Donations*

The Council desire to acknowledge gratefully the gift of £250 from the Society of British Aircraft Constructors to the funds of the Society; Journals and £2 towards the expenses of the recent Reception from Sir Mackenzie Chalmers; a donation of £1 from Mr. Holt Thomas for the same purpose; and a donation of £1 1s. 0d. from Mr. R. Dunlop to the Library Fund.

### *Lecture*

The subject of Mr. Henshaw's lecture on Thursday, December 2nd, will be "Valve Steels." Mr. Henshaw is the Technical Director of Kayser, Ellison and Company, Limited. Colonel the Master of Sempill, A.F.C., Associate Fellow, Chairman of the Society, will take the chair.

### *Wilbur Wright Memorial Lecture*

The Wilbur Wright Memorial Lecture for 1927 will be delivered by Professor Prandtl. The title of the lecture and other details will be announced in due course.

### *Lecture Programme, 1926-1927, Second Half*

Thursday, January 6th, 1927.—Major B. C. Carter, A.R.C.Sc., D.I.C., Associate Fellow: "Dynamic Forces in Aircraft Engines."

Thursday, January 20th.—Mr. H. Glauert, Associate Fellow: "The Theory of the Autogiro."

Tuesday, February 1st.—Joint Meeting with the Institution of Automobile Engineers, at 7.0 p.m., at the Royal Society of Arts. Mr. A. H. R. Fedden, Fellow: "Supercharging for Aero Engines."

Thursday, February 17th.—Major R. H. Mayo, O.B.E., Fellow: "The Design and Operation of Commercial Aircraft."

Thursday, March 3rd.—Mr. L. W. Bryant, B.Sc., A.R.C.Sc., Associate Fellow, and Mr. S. B. Gates, M.A.: "The Spinning of Aeroplanes."

Thursday, March 17th.—Mr. M. A. Giblett, M.Sc.: "Line Squalls."

Thursday, March 31st.—Mr. E. G. Richardson, M.Sc., Ph.D.; "Recent Model Experiments in Aerodynamics."

Thursday, April 7th.—Subject to be announced later.

Thursday, April 28th.—Major R. E. Penny: "Seaplanes."

### *Students' Section*

The Inaugural Meeting of the 1926-27 Session was well attended by an enthusiastic audience. Mr. F. Handley Page, C.B.E., Fellow, gave an address on "The Future of Aviation." Lieut.-Colonel I. A. E. Edwards, C.M.G., took the chair and presented to Flying Officer R. Linton Ragg, R.A.F., the Pilcher Memorial Prize and the cash prize given by Lieutenant R. V. de Aboim, B.N., unanimously awarded by the Council for the paper "Experimental Flying from the Pilot's Point of View."

The following provisional programme has been arranged for 1927:—

Thursday, January 27th, at 7.0 p.m.—In the Library. Lecture and Discussion, "The Possibilities of Metal Construction with Special Reference to the Metal Skin," by Mr. R. M. Hayes.

Saturday, January 29th.—Visit to Croydon Terminal Aerodrome. Afternoon. Captain Gillman will show the party round.

Thursday, February 10th, at 7.0 p.m.—In the Library. Lecture and Discussion on "The Articulated Connecting Rod," by Mr. E. Fearn.

Saturday, February 26th.—Visit to the De Havilland Aircraft Works, Stag Lane Aerodrome.

Thursday, March 10th, at 7.0 p.m.—In the Library. Lecture and Discussion. (The title of Mr. W. T. Sandford's paper will be announced later.)

Thursday, March 24th, at 7.0 p.m.—In the Library. Informal Discussion on "Lighter-than-Air Craft *v.* Heavier-than-Air Craft."

Saturday, April (date to be announced later).—Visit to Vickers, Limited, Weybridge.

Thursday, May 5th, at 7.0 p.m.—In the Library. Paper and Discussion, "Polar Exploration and Survey by Air," by S. Scott Hall.

Thursday, May 19th.—In the Library. Short Lecture by a Fellow or Associate Fellow, to be followed by a general informal discussion.

May or June.—Whole day visit, in course of arrangement.

### *Bronze Medal*

Students are reminded that the Bronze Medal of the Society is available for award annually for the best paper by a Student published in the Journal. This is apart from the papers read before the Students' meetings.

### *Coventry Branch*

On Thursday, November 18th, Mr. E. G. Bilham, B.Sc., Superintendent of Instruments at the Meteorological Office, gave a lecture on "Meteorology in Aviation." This proved very interesting to a large audience.

Major F. M. Green, Fellow, took the chair. In the course of his lecture Mr. Bilham stated that records were taken up to a height of no less than 13 miles by firing shells, kites and small free balloons. The importance of the close and necessary connection between meteorology and aviation was emphasised.

The next lecture is arranged for December 7th, when Mr. F. Handley Page, C.B.E., Fellow, will address the branch on "The Control and Stability of Aircraft."

### *R.38 Memorial Prize*

Members and others are reminded that the closing date for the receipt of names of entrants for the R.38 Memorial Prize, 1927, is December 31st. The prize is offered annually for the best paper received by the Society on some

subject of a technical nature in the science of aeronautics. Other things being equal, preference will be given to papers which relate to airships. The prize is open to international competition, and is of the value of twenty-five guineas. The papers must be sent in by March 31st, 1927. A copy of the regulations can be obtained from the Secretary.

### *Scottish Branch*

The arrangements for the final winding up of the Scottish Branch have now been completed. Such a winding up became necessary under the new branch rules. A scheme is now being discussed to form local branches in Scotland, corresponding to those already formed or being formed in England. All members of the late Scottish Branch have been written to and informed that they can now join direct to the Head Office. It is hoped that any members who would like to form a new branch in any part of Scotland will communicate as early as possible with the Secretary.

### *Library*

The following books and pamphlets have been recently received and placed in the Library:—"All the World's Aircraft, 1926"; "The Book of the Aeroplane," J. L. Pritchard; Technologic Papers of the Bureau of Standards, Washington, Nos. 237, 287, 293, 320, and List of Publications of the Bureau, 1901-1925; N.A.C.A. Technical Notes, Nos. 246 and 247; N.A.C.A. Reports, Nos. 239, 242 and 244; A.R.C. R. & M., Nos. 989, 995, 1006, 1007, 1009, 1015, 1017, 1019, 1027, 1029, 1032, 1036, 1037 and 1038; Air Publication No. 916, 4th Edtn., Avro Type 504 K. 100 h.p. Mono.; "Air Warfare," W. C. Sherman; "Un Volo di 55,000 Chilometri," F. De Pinedo; "Methods of Air Analysis," J. S. Haldane; Annual Report of the Meteorological Committee to the Air Council for the year ended 31st March, 1926; Memoirs of the Royal Meteorological Society, Vol. I., Nos. 2 and 3; "The History of Munitions Supply in Canada, 1914-1918," D. Carnegie; Abhandlungen aus dem Aerodynamischen Institut an der Technischen Hochschule Aachen, Heft 5, "Theory des Segelfluges," W. Klemperer; Rapports, Semaine d'October, 1925, Société Francaise des Electriciens; Second Report of the Gas Cylinders Research Committee (Periodical Heat Treatment), Department of Scientific and Industrial Research; Report on Civil Aviation, Department of Defence, Dominion of Canada; and Photostat and typed copy of Knight's Diary on Wrangel Island, September, 1921—March, 1923.

The photostat and typed copy of Knight's Diary on Wrangel Island has been presented to the Society by the generosity of Mr. Griffith Brewer, Fellow.

Members are reminded that they may borrow books from the Library, either in person, or by post on condition that they pay the cost of postage in both directions.

### *Forthcoming Arrangements*

Thursday, December 2nd, 6.30 p.m.—At the Royal Society of Arts. Mr. P. H. Henshaw, "Valve Steels." Colonel the Master of Sempill, Chairman of the Society, in the chair.

Saturday, December 4th, 10 a.m.—Visit to Messrs. D. Napier and Son, Ltd., Acton. (Number visiting limited to ten.)

Tuesday, December 7th, 5.30 p.m.—Council Meeting.

Thursday, December 9th, at 7 p.m.—In the Library, Students' Lecture and Discussion on "The Possibilities of the Two-Stroke Cycle for Aircraft Engines," by Mr. C. G. Hutchison. Wing Cdr. T. R. Cave-Browne-Cave, C.B.E., Fellow, in the chair.

Thursday, December 16th, 6.30 p.m.—At the Royal Society of Arts. Wing Commander C. D. Breeze, A.F.C., R.A.F., "The Training of Aircraft Apprentices." Colonel the Master of Sempill, Chairman of the Society, in the chair.

Saturday, December 18th, 10 a.m.—Visit to the Hawker Engineering Company, Limited.

### *Correction*

Owing to a regrettable oversight it was omitted to state that the lecture by Mr. H. E. Wimperis, in the November issue, on "The Relationship of Physics to Aeronautics," was an abstract of one delivered before the Institute of Physics on June 7th, 1926.

J. LAURENCE PRITCHARD, *Hon. Secretary.*

# PROCEEDINGS

## First Meeting, First Half, 62nd Session

The First Meeting of the 1926-27 Session was held in the Lecture Theatre of the Royal Society of Arts, John Street, Adelphi, London, W.C.2, on Thursday, October 7th, when Colonel the Master of Sempill, the new Chairman of the Society, delivered his Inaugural Address, entitled, "Aero Engine Fuels of To-day and To-morrow." Air Vice-Marshal Sir Sefton Brancker, the retiring Chairman of the Society, presided.

The retiring Chairman, opening the proceedings, said he had a very easy and a very pleasant task in introducing the Society's new Chairman—easy because he really did not require any introduction; pleasant because he had known the Master of Sempill from his start in aviation. Colonel the Master of Sempill was one of those remarkable combinations of an active and a really brilliant pilot and a man with high scientific attainments and great technical experience. When he had joined aviation at the beginning of the war he had broken pretty well all regulations, for he had managed to get into an aeroplane and fly away without any previous dual control instruction. He himself had known the Master of Sempill well since the beginning of the war, and regarded him as a great asset to aviation. They had been together on many occasions, but he considered the greatest occasion was when he (Sir Sefton Brancker) was sent on a mission to the United States, in 1918, and Colonel the Master of Sempill was appointed his personal assistant. Within a week of their arrival all the American experts had realised that his (Sir Sefton Brancker's) technical ability was really nil, and he was relegated to what might be called the "glad hand" side of the business, whilst they all followed the Master of Sempill about wherever he went and listened to every word he had to say. He created a great name for himself, and on his (Sir Sefton Brancker's) subsequent visits to the United States, his old friends of 1918 always asked about the Master of Sempill and what he was doing.

## AERO ENGINE FUELS OF TO-DAY AND TO-MORROW

BY COLONEL THE MASTER OF SEMPILL, A.F.C., A.F.R.AE.S.

### *Foreword*

I feel most sincerely the weight of the great honour that has been done me in electing me as Chairman of so distinguished a Society, which most certainly does occupy a unique position as the oldest Aeronautical body in the world. The diffidence with which your very distinguished Chairman of the Session now closed assumed office, makes me wonder as to how I can most suitably step into his shoes, and, in particular, solve the difficulty of delivering an inaugural address which will not be too unworthy to rank with the papers of the high standard of the past.

The Royal Aeronautical Society has, in common with almost every other Society or Institution, suffered from the after effects of the War. One of the questions that has engaged the attention of your Chairman and Council, has been to find means to repair these deficiencies and to increase the membership and sphere of activities of the Society to the greatest extent. Your late Chairman, suffering, as he himself admits, from an incurable disease (supreme belief in aviation) has turned some of his abundant and heavily-taxed energies on to these

problems with good effect. Good progress has been made and the lately announced grant from the Guggenheim Fund of America in aid of the Society's activities, is by no means the only example of this. It is, however, the privilege of the British people to support their own Society, and it is hoped that the very fine lead now given by America will be followed up over here. I cannot let this occasion pass without bringing to your notice the valuable assistance given by Major Mayo in this particular case.

Before passing on to the Lecture you will perhaps allow a few remarks to be made on some of the more important happenings during the past year. The most important occurrence undoubtedly has been the removal of the restrictions imposed on Germany, which will now allow the real development of Air Transport in Europe which was not before possible. Events have shown that great progress has been made in the short time that has elapsed since the fetters on European Commercial Air Transport have been loosened.

Second to this probably comes the many arduous and astoundingly successful demonstrations of British air-cooled engines. Air cooling has gained many new adherents and is beginning to achieve a measure of the success that has been prophesied by a few for some time past. The building of British air-cooled engines in various countries in Europe and in the Far East, is a great mark of the world's recognition of our supremacy in this particular direction.

The advent of the Hill tailless aeroplane and the Autogiro open up possibilities, the full effects and particular direction of which are a matter for a great deal of speculation. One of the interesting effects of this great endeavour to obtain increased safety in flight, has been that the general public at last commences to take a much closer interest in the characteristics of different aircraft, and this must lead to good.

Last, but by no means least, this year has shown in more directions than one the practical qualities of the light aeroplane with its small air-cooled engine. It has certainly opened up a vista of flying in an economic manner not before considered possible. The recent *Daily Mail* competition has fulfilled a very useful purpose, as although its direct practical benefits may be open to considerable speculation, there is no doubt that the attention focussed on light aeroplanes as a whole will have a large effect not only on the more extended use of those successful designs which exist to-day, but in the production of others with, one hopes, even greater virtues.

The fact that greater attention is being paid by the Air Ministry to research in general and, in fact, matters technical as a whole, gives us the satisfaction of not only congratulating those officials who direct these matters, but ourselves, as we, in common with others, have agitated continuously, apparently with some result.

I had hoped to read a paper dealing with Commercial Aviation and had in view the following title: "The Upkeep, Maintenance and Repair of Commercial Aircraft, their Engines and Equipment." Too little has been said on such an important, although possibly a not very exciting subject, and I have been unable to find any carefully tabulated information, although material in some form must exist.

It is very largely by a careful and analytical study of the behaviour of the existing equipment that progress in future designs can be made, and it would appear that if there is an idea prevalent that information of this description is a kind of trade secret not to be divulged that such is most strongly to be deprecated.

Surely, if we really wish to encourage and demonstrate the advantages of Commercial Air Transport, we must help each other and approach this matter as your past Chairman, Sir Sefton Brancker, recently remarked: "In a spirit of altruism and broad-mindedness."

In any event I had to give up the idea of reading a paper on such a subject as Imperial Airways could not see their way to supplying information as to the behaviour of their own fleet. I believe, however, that such a paper is going to be delivered by their Technical Superintendent before another Society.

In taking therefore the subject of Fuels I hardly think I need apologise, except for my shortcomings, as the subject is one of such overwhelming importance and has not been dealt with at any great length in recent years before the Society.

It is impossible in the time allotted, even were I able to do so, to put before you anything like an exhaustive treatise on this involved and by no means fully explored subject. It is, however, to be hoped that others will follow and make good the many omissions that will undoubtedly exist.

I would like at this stage to express my gratitude to the Air Ministry, and in particular to the Director of Scientific Research and his Staff at South Kensington, in particular Professor Callendar, Captain King and Flight-Lieutenant Sims, not only for the permission given to make use of certain data, but for assistance given in one form and another by undertaking various tests, etc. Thanks should be similarly extended to the Director of Aeronautical Inspection. In addition I am extremely indebted to the chief chemists of the Anglo-Persian Oil Company and the Shell Company, Dr. Dunstan and Mr. J. Kewley, and their assistants, Dr. Thole and Captain Marshall. Valuable help has also been received from Sir Frederic Nathan and Colonel Tizard of the department of Scientific and Industrial Research. It would be almost needless to add that the help offered by Mr. Ricardo has been invaluable and indispensable. I am also indebted to Mr. Fedden, of the Bristol Company, Major Searight and Captain Dodson, of Messrs. Hobson, Ltd., in particular for their investigations on the characteristics of cracked spirit.

The title of the paper was chosen before the paper was born and, as is not unusual under such circumstances, it has been difficult to make the two fit well. It is usual, and in the case of the petroleum industry, which goes back into a past of which we know almost nothing, extremely interesting to study the historical side of the subject.

### *History*

The Bible (Genesis IX. 3) has many references to petroleum products; for instance we learn in the building of the Tower of Babel: "Slime had they for mortar," the slime being bitumen. This fact is somewhat confirmed by Herodotus, who refers to the use of a similar material in the building of the walls of Babylon. In Maccabees II. 1, 18-36 Nehemiah poured what was termed "thick water" on the sacrifices which subsequently were ignited by the heat of the sun. The "water" was called Nepthar. Pliny and others mention the use of "Sicilian Oil" for illuminating purposes.

The Dead Sea, originally named the Lacus Asphaltites, provided bitumen, which, according to Diodorus, the celebrated historian of Cæsar's time, was sold to the Egyptians for embalming purposes.

In the East the petroleum industry was a going concern before the birth of the Christian era, as the Japanese and Chinese sunk wells and even ventilated the shafts by means of bellows. It is said in the Japanese history called Kokushiriyaku that the rock-oil or "burning water" was found in Echigo in the reign of Tenjitenno, which was about 1,260 years ago, or about A.D. 615, and that was probably at Kusodzu where there are very old oil exposures as well as dug wells. The method of digging petroleum wells in Japan is thus described: "The present method of working is very simple, a method that has probably grown into its present form in the course of centuries of experience and is now apparently practised in all the oil regions with little or no variation. The digging is done by

two men, one of whom digs in the morning from 9 till noon and the other from noon till 3. The one who is not digging works a large blowing machine or bellows that continually sends fresh air to the bottom of the well. The blowing apparatus is nothing but a wooden box about six feet long and three feet wide by two feet deep with a board of the same length and width turning in it upon a horizontal axis at the middle of each long side of the box and with a vertical division below the board between the two ends of the box. The workman stands upon the board and walks from one end of it to the other alternatively pressing down first one foot and then the other. At his first step on each end he gives a smart blow with his foot so as to close with a jerk a small valve (0.3 feet square) beneath each end of the board, a valve that opens by its own weight when the end of the board rises. The air is therefore driven first from one end of the box and then from the other into an air pipe about 0.8 feet square and placed in one corner of the well."

Much later, about 1600, one Magara found oil which he subsequently distilled. The distillate was sold as an illuminant. It is thought that this provides the first case where an attempt was made to split up crude oil into its components.

The redoubtable and ever famous Marco Polo, writing in Baku at the end of the thirteenth century, remarks on "a fountain from which oil springs in great abundance inasmuch as a hundred ship loads might be taken from it at one time. This oil is not good to use with food, but it is good to burn and is also used to anoint camels who have the mange."

The fire-worshippers of Baku, which was originally Persian territory, came in their thousands to worship the everlasting fire. Jonas Hanway's account of 1754 is of interest: "What the Guebers or fire-worshippers called the everlasting fire is a phenomenon of a very extraordinary nature. This object of devotion lies about 10 miles N.E. by E. of the city of Baku. There are several temples built with stone supposed to have all been dedicated to Fire. Amongst these is a little temple at which the Indians now worship. Here are generally forty or fifty of these poor devotees who come on a pilgrimage from their own country. A little way from the temple is a low cleft of rock in which there is a horizontal gap two feet from the ground nearly six feet long and three feet broad out of which issues a constant flame in colour and gentleness not unlike a lamp that burns with spirit only more pure. When the wind blows it rises sometimes eight feet high, but much lower in still weather. They do not perceive that the flame make any impression on the rock. This the Indians worship and say it cannot be resisted, but if extinguished will arise in another place. The earth round this place for about two miles has this remarkable property, that by taking up two or three inches of the surface and applying a live coal the part which is uncovered immediately takes fire. The flame makes the sail hot, but does not consume it. Any quantity of this earth carried to another place does not produce this effect. If a cane or even a tube of paper be set about two inches in the ground, confined and closed with earth below and the top of it touched with a live coal and blown upon, immediately a flame issues without burning either cane or paper provided the edges be covered with clay; this method they use for lighting their houses which have only the earth for the floor. Three or four of these lighted canes will boil water in a pot and thus they dress their victuals." These and many more references of interest are to be found in that monumental work on petroleum by Sir Boverton Redwood.

But Baku alone had no monopoly of such phenomena, as in 1667 mention is made of natural gas being found at Wigan. The water at this spot was said to burn like brandy and to provide enough heat for cooking eggs, etc.

One of the great pioneers of more modern times was James Young, who about 1850 built a refinery in Derbyshire for the treatment of crude petroleum found in a coal mine. Subsequently the flow of oil came to an end, and Young

being a man of energy and determination turned his attention to distilling coal and shale and thus laid the foundation of the Scottish Shale Oil Industry that will, one feels suite sure, in course of no great time, be revived as a result of rapidly impending economic changes.

In America petroleum products were sought after and used by that race of Mound Builders, as they are commonly known, who preceded the Indians. Under the name of Seneca Oil it was used as a cure for numberless complaints. It was not, however, until 1856 that a Colonel Drake drilled the first well sunk in the United States with the sole intention of finding oil. Oil was found and Young's ideas on distillation and refining were modified and put into practice. It is a not uncommon, but none the less regrettable fact, that Colonel Drake died a very poor man. In this year (*i.e.*, 1856) the petroleum products marketed in the U.S.A. totalised some 300 tons. Up to the year before the commencement of the war the figure was 35,000,000 tons; at the end of 1924 about 74,000,000 tons.

### *Sources of Supply*

The question of the available supplies of petroleum has always been a field for speculation both conservative and the reverse. At the meeting this year of the British Association the exhaustion of the world's oil supplies was forecasted. More recently an official report issued by the competent authority of the U.S.A. places the available domestic stocks as being sufficient for a very short period. It must obviously be a more than ordinarily difficult task endeavouring to peer into the future in so far as oil supplies are concerned, and the prognostications made in the past under somewhat similar circumstances do not fill one with great confidence.

From the United States, who incidentally consume about twenty times more petrol, or gasolene as they call it, than we do, we have heard before of the impending exhaustion of supplies, but these calculations were entirely upset by the opening up of a large Californian field which resulted in the record production of over 720,000,000 barrels, or about 50 per cent. more than the previously estimated peak production.

Sir Robert Waley Cohen, of the Royal Dutch Shell Group, has pointed out that there is little to be gained by cramping the development of our own generation in the hope that we may benefit a future one. The truth of this assertion may be gauged by the fact that anyone endeavouring to estimate the future source of power in the world some sixty years ago would have disregarded oil. As to the length of life of existing fields great doubt exists. Many fields have become largely exhausted or the production is falling off, as for example in the famous South Russian fields and others. There can be no doubt that the production of petroleum is still going on where the conditions are favourable, but this fact is of small comfort to us to-day. The petroleum supplies now being drawn on are being drawn from reservoirs which when emptied of their present contents will remain barren. Fresh fields will undoubtedly be opened up, but where, no one of the greatest experts can accurately forecast, far less can he estimate the quantity that will be found. In talking of exhaustion complete drainage of the fields must not be visualised, as on the average probably not more than 35 per cent. of the oil present is brought to the surface. It should, however, be pointed out that the methods of obtaining the oil out of the ground have been greatly improved. In fact the possibilities in this direction have not as yet been fully realised.

To-day petrol is, generally speaking, the most valuable of the various products obtained from petroleum, in fact it has been said that petrol pays for the cost of the crude oil, kerosene for refining and fuel oil for marketing, leaving lubricating oil for profit. Although this may be true in some cases it cannot be in

all, as the character of the various crude oils differs so largely in the yields of the before-mentioned products. Some crudes may produce as much as 50 per cent. of petrol, others none.

Although it is certain we shall not see a recurrence of the conditions that pertained some twenty-five years ago when large sums were expended on equipment designed to carry petrol to some harmless spot where it might be burnt, it is not improbable that the present price difference between the cost of this commodity and fuel oil may be revised, if not reversed, due to the influence of cracking. The vested interests in the motor car world will probably hold up any change from using light fuels for some time in spite of the advantage of a technical nature that might accrue. Everyone is probably aware that a somewhat similar situation exists to-day in regard to town gas supplies where tremendous improvements are technically possible.

The average crude oil from American sources yields approximately 50 per cent. of gas and fuel oil, 25 to 30 per cent. of petrol and 10 per cent. of kerosene, the remainder being lubricating oil, paraffin wax, asphalt, etc. These figures take no account of cracking.

A certain amount of criticism has lately been levelled at the large oil groups and their supposed wasteful methods of handling. This criticism hardly bears even a moderately close scrutiny, as although waste does occur in drilling, refining and various other operations affecting the crude oil, it is because the groups are not large enough. Oil has essentially got to be handled on the grand scale, and it is only when a field comes under one control, as in the case of the Anglo-Persian, that its economic exploitation is at all possible. The large oil producing concerns give the public excellent service in the way of comparative stability of prices and wide distribution of supplies. Another very valuable service is that relating to research work, which has been undertaken with the great thoroughness that only a powerful organisation can afford. The knowledge of the fact that nearly 70 per cent. of the world's production is controlled by concerns independent of the three large organisations will come as a surprise to many.

It would be unwise to become unduly distressed as to the oil supplies of the world as everything points to the existence of large supplies as yet untapped, and further the greater introduction of operations such as cracking are daily tending to ease the immediate situation regarding petrol supplies and allow us more time to explore the future.

The bulk of the world's oil supplies is produced by the United States and Mexico (which produce over 80 per cent.) and Russia. Then follow Persia, the Dutch East Indies, Roumania, Venezuela, Burmah, Galicia, Peru, Japan, Trinidad, Argentine, Egypt, France, Canada, Germany and Italy. The crude oil from the different fields varies enormously, as is to be expected seeing that they are drawn from strata of different geological ages and formed from a variety of materials and in a variety of ways. The following tables and Fig. 1 serve to show the sources of the world's supplies.

1.—Relative Total World's Production of Crude Petroleum up to and including 1925.

| | | |
|---|---|---|
| U.S.A. and Mexico ... ... | 9,966,321,000 | barrels. |
| Russia ... ... ... ... | 2,105,643,500 | ,, |
| Dutch E. Indies ... ... | 315,032,500 | ,, |
| Roumania ... ... ... | 224,023,800 | ,, |
| Poland ... ... ... ... | 191,445,000 | ,, |
| Persia ... ... ... ... | 182,568,000 | ,, |
| India ... ... ... ... | 165,638,500 | ,, |
| S. America ... ... ... | 126,035,000 | ,, |
| Other Countries ... ... | 178,111,500 | ,, |

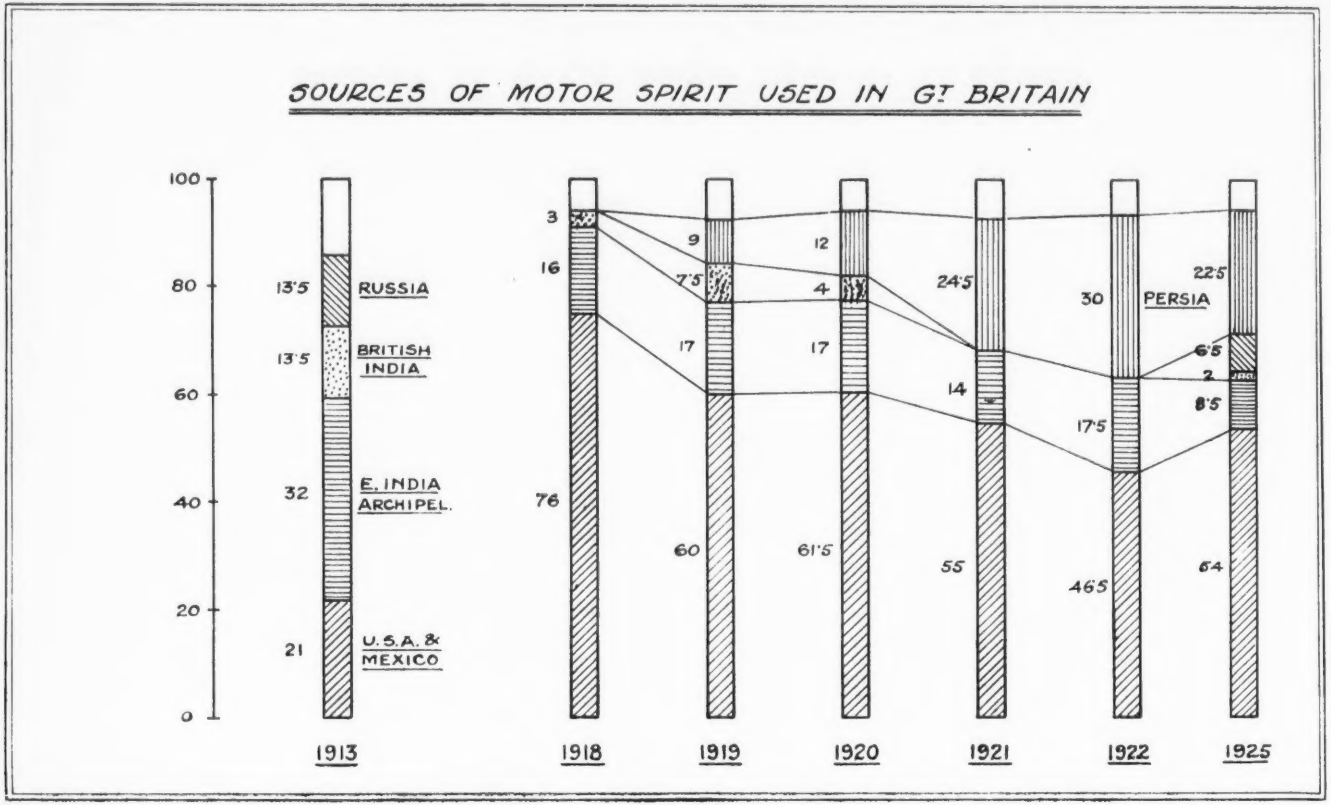

SOURCES OF MOTOR SPIRIT USED IN Gt BRITAIN
100
80
60
40
20
0
13·5
RUSSIA
13·5
BRITISH INDIA
32
E. INDIA ARCHIPEL.
21
U.S.A. & MEXICO
1913
3
16
76
1918
9
7·5
17
60
1919
12
4
17
61·5
1920
24·5
14
55
1921
30
PERSIA
17·5
46·5
1922
22·5
6·5
2
8·5
64
1925

FIG. 1.

2.—Imports into U.K., 1925, Crude Petroleum, Crude Distillate and Kerosene for Refining and Cracking.

| | |
|---|---|
| Persia ... ... ... ... | 10,586,500 barrels. |
| S. America ... ... ... ... | 4,304,000 ,, |
| U.S.A. and Mexico ... ... | 781,500 ,, |
| Russia ... ... ... ... | 349,500 ,, |
| Roumania ... ... ... ... | 136,000 ,, |
| British W. Indies ... ... ... | 43,000 ,, |
| Others ... ... ... ... | 350 ,, |

3.—Imports of Motor Spirit into U.K., 1925.

| | | |
|---|---|---|
| U.S.A. and Mexico ... ... | 271,605,500 | imperial gallons. |
| Dutch Borneo ... ... ... | 34,642,000 | ,, ,, |
| Russia ... ... ... ... | 33,111,500 | ,, ,, |
| Persia ... ... ... ... | 19,680,000 | ,, ,, |
| British India ... ... ... | 9,160,000 | ,, ,, |
| Dutch W. Indies ... ... ... | 8,689,000 | ,, ,, |
| Roumania ... ... ... ... | 7,824,000 | ,, ,, |
| Straits Settlements ... ... | 7,457,500 | ,, ,, |
| British W. Indies ... ... ... | 6,298,000 | ,, ,, |
| Others ... ... ... ... | 6,345,500 | ,, ,, |

Fig. 1.

The crude oils may be roughly divided into two groups :—

(1) The paraffin base oils.
(2) The asphalt base oils.

The former contain a relatively high percentage of aliphatic hydrocarbons, the latter cyclic hydrocarbons. It is from this latter class that the best aviation spirit considered as a straight-run product without the addition of benzol or dopes is usually obtained. This classification is very general and there are certain notable exceptions.

As has been mentioned, these various crude oils exhibit a great diversity of character, and until considerably more research work has been undertaken no proper system of classification can be evolved. So far petroleum only has been referred to, and although without question the most important source of supply at the moment, there are other sources the growing importance of many of which must claim our attention.

## *Oil Shale*

The history of the Scottish shale oil industry has been marked by a series of tremendous fluctuations. At the moment it is unfortunately not in a very healthy condition, but it is fair to assume that it will undoubtedly pass on to a better period of prosperity. In this event the vast deposits of oil shale in England will be opened up and improved methods of refining will enable the sulphur trouble to be dealt with. In the early days of this industry torbanite—a species of cannel coal with a yield of up to 120 gallons per ton—was used. Subsequently supplies became exhausted and oil shale with its much lower yield of 20 to 50 gallons per ton was substituted. The increased value of the by-products, notably ammonium sulphate, enabled this industry to hold its own against the petroleum industry for a longer period than would otherwise have been possible.

While touching on this home industry, which is surely worthy of all the encouragement it can be given, a word on the possibilities of the occurrence of petroleum in these islands may not be out of place.

As has been mentioned, even before the days of James Young seepages of petroleum and the occurrence of natural gas had been remarked on in various parts of the country. It was not, however, until the war that a serious attempt, in the light of modern knowledge and with the advantage offered by modern equipment, was made to drill for oil. These attempts did not meet with any large measure of success, although the Derbyshire (Hardstoft) crude oil produced an excellent kerosene and a remarkably good quality of cylinder oil. In the end, however, those controlling operations decided against further expenditure and the matter was dropped. It must, however, be added that there are some who still favour a continuance of operations in certain areas, and support is found for such a view by the measure of success attained in France and Germany in strata of similar geological age to that in which oil is thought to be present over here.

### *Coal By-Products—Motor Benzole, etc.*

The introduction of benzol recovery, a process started by Brunck some thirty-five years ago, has gained an increasingly wider application. The recovery of this and the other valuable by-products of our coal supplies is as yet in its infancy, and the terrible waste that is going on is at last beginning to attract wide attention. The low temperature carbonisation of coal has been a matter on which considerable sums have been expended both by the Government and by sundry companies. It would seem as though this problem has now reached the point where economic utilisation of at least one of the processes tried becomes possible, although admittedly this has to be proved. The range of by-products obtained is large in addition to the smokeless solid fuel and the oil, which is but a small part. The petrol distilled from such an oil proves to have, as would be expected, valuable properties from the standpoint of its use in aero engines.

Bergius in Germany has pioneered in the field of the hydrogenation of coal, employing pressures of over 100 atmospheres and at temperatures around 400°C. Coal so treated has been shown to yield a large percentage of oil, a portion of which should be a valuable fuel for I.C. engines. At present nearly all the petrol used in this country for aero engines has between 20 and 30 per cent. of benzol added to it. In the event of war the bulk of these supplies of benzol would be required for the making of explosives. During the last war such supplies as existed were added to by the derivation of toluene from petroleums of Eastern origin. There can be no doubt that the more economic use of our coal is a matter of the first national importance viewed from every standpoint. The wider application of processes for the winning of the by-products and the improvement of absorption methods for the removal of products from coke oven gases, etc., will increase the supplies of home-produced fuel.

### *Power Alcohol*

The supplies of petroleum, coal and like minerals cannot be inexhaustible, particularly as they furnish all the liquid fuels used to-day in I.C. engines. It is therefore obvious that any means of producing another suitable fuel in quantity should be most closely investigated. Alcohol is such a fuel, and any success that has been met with in its production or experimental use is due to the untiring efforts of Sir Frederick Nathan, coupled with the exhaustive technical work of Ricardo in particular and others. Broadly speaking, alcohol can only be economically produced from waste materials or natural products of small value; in fact, it may be said that where materials have a food value, that value is the highest. The possibilities of producing alcohol in this country from vegetable material grown here is stated in the first report of the Fuel Research Board as being not economically possible if any quantity is desired. Even in the Dominions and Colonies considerable difficulties are seen as storage charges and freight would prove a serious item of expenditure.

There are other sources of supply which might be utilised to some extent, such as straw, sulphite liquor from paper pulp mills, waste molasses from sugar refining and waste wood. It is probable that the prolific vegetation of tropical countries may become available when a process to extract the alcohol therefrom has been found. Mr. Monier-Williams in his treatise on "Power Alcohol" admits that even if the raw material were to cost nothing at all, it would be extremely difficult for alcohol to compete with petrol. At the time this work was written the price of petrol was about 1/- per gallon more than its price to-day. It seems fair to assume that there will be no sudden change, but rather a growing use of alcohol in fuel mixtures of petrol and/or benzol. As the price of the two latter will gradually show a tendency to rise, so will an impetus be given to the production of alcohol. One complication that arises in regard to power alcohol is that of finding a suitable denaturant that will satisfy the regulations of the Excise authorities. Up to the present no compound properly fulfilling all the requirements has been found. A general agreement on this important point is most necessary so as to allow commercial exploitation without difficulty, as the present varied regulations even within the Empire would give rise to considerable difficulty.

The production of synthetic methyl and other alcohols ("Synthol") is being undertaken in France and Germany from water gas. There are of course other methods of production than through water gas, as for example ethylene and carbide. The ethylene process is not likely to be utilised in this country to any appreciable extent, although a large plant is said to be in process of erection in France. The same may be said of the carbide process, and viewing coal as a source of alcohol supply, the method of production through water gas is thought to have possibilities in this country, in particular when the scope of the process has been widened as a result of experience.

Several methods have been tried for the extraction of alcohol from wood with varying results. Local conditions will probably dictate the process most suitable. The Prodor and Classen methods of production have been greatly improved, the latter in particular, which shows great promise.

The utilisation of other cellulosic materials has already been touched on.

A recent report to the Minister of Agriculture of a special Committee under the chairmanship of Sir Robert Robertson states, after careful inquiry, that the processes that enable alcohol to be produced from wood or water gas alone seems likely to add to the available liquid fuel supplies of the country. Having now considered in a very general way the sources of supply of liquid fuels, it will be well to review briefly the general character of the fuels themselves, and it will probably be convenient to divide them under the following headings:—

1. Petroleum (straight-run, casing head and cracked products).
2. Shale oils.
3. Coal products.
4. Power alcohol.

### *General Characteristics of Petrol and Other Light Fuels*

A word or two on the most desirable qualities of a good petrol may not be out of place here. It was not very long ago when petrol was judged almost entirely by its gravity, smell and colour. In fact, a very large portion of the general public in this country at least still attach great importance to these, the former in particular. The question of smell has really only got importance from an æsthetic standpoint, as the various classes of hydrocarbon that go to make up petrol each have distinctive smells that cannot be eradicated. This question is largely one of custom as the public have been educated to the smell of straight-run products, but have not yet become used to the characteristic

smell of cracked products. Again, the question of colour has been treated to an importance that it hardly deserves. The production of a perfect water-white product is in certain cases extremely difficult and certain refineries in America have periodically coloured this product red so as to disguise the fact that it was not water-white. The importance of gravity, as has been remarked before, has been very much over-emphasised. In fact, specific gravity alone may be most

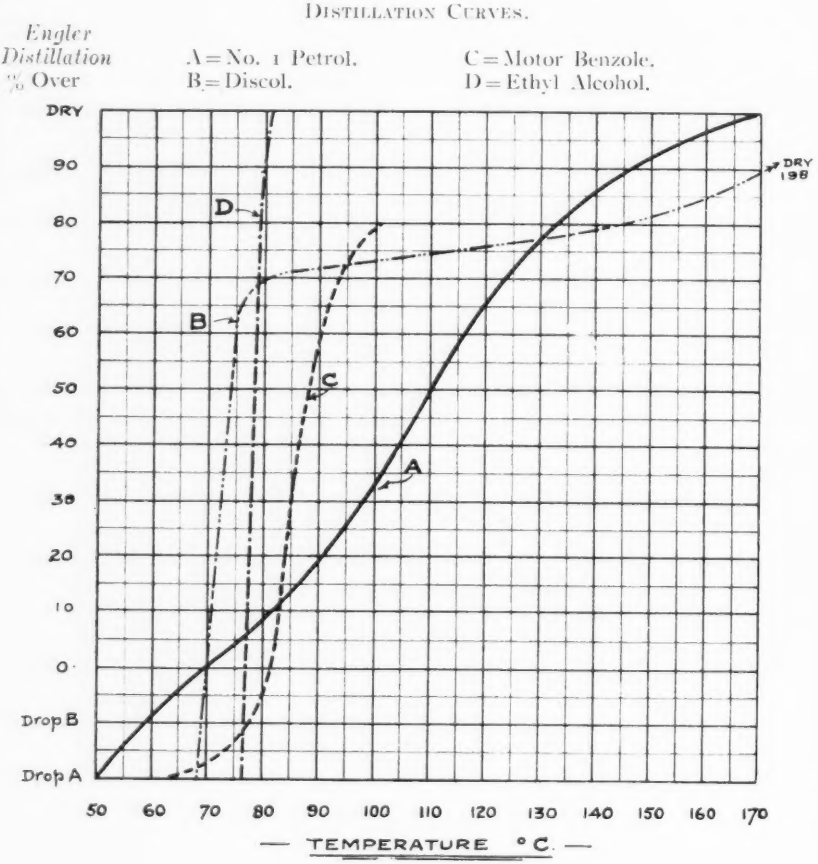



FIG. 2.

misleading when we consider that certain classes of hydrocarbons present in ordinary petrol have the same specific gravity as certain lubricating oils. Generally, too, the tendency was to demand a petrol of low specific gravity. This, of course, assuming no doping element be added, gives a petrol that would most certainly fail to perform well even in an engine of moderate efficiency.

Towards the end of the war the fuel situation, particularly that relating to fuels suitable for aero engines of high efficiency, became better understood, and since then a great deal of valuable research work has been carried on. Although the available knowledge to-day seems great, the subject is so vast and complex as to have hardly been touched at all.

One cannot pass without mentioning the pioneer work of inestimable value of Mr. Ricardo and his assistants for the Royal Dutch Shell Group, the greater part of which is public knowledge. Where Ricardo so ably led, others have followed and added useful knowledge. Amongst them should certainly be mentioned Professor Callendar with his assistants Capt. King and Flight-Lieut. Sims, and also Drs. Moore, Ormandy, Craven, Mardles, and a few others. The resources of the Anglo-Persian Oil Co. have also become available for public consumption to a great extent. In America the work started by Midgley and Boyd has contributed a great deal of valuable data and has drawn in others to this almost inexhaustible field of research. All this work has served to point out the important characteristics desired in aviation spirit in particular. The most important property is that of its highest useful compression ratio. This is the compression ratio beyond which, the carburettor and magneto being set for maximum power, any increase results in detonation or pinking with a consequent decrease in power and other evil effects. Every class of hydrocarbon has a limiting compression. Of the main classes present the aromatic hydrocarbons are the best from the standpoint of anti-pinking followed by the naphthenes and paraffins, the latter being by far the worst offenders. Another important factor that has to be considered is the boiling range. By this means it is possible to judge whether the product is well graded and possesses sufficient volatile fraction to allow of easy starting and does not contain those of too high a boiling point that would interfere with lubrication. In addition there are numerous other tests that will tell as to whether any undesirable constituents naturally present in the crude oil remain or have been left accidentally as a result of imperfect treatment in the refinery. The ascertaining of the chemical composition of the spirit is a matter of extreme difficulty; in fact, any form of classification can be but a general classification of the percentage of paraffin, naphthene and aromatic hydrocarbons present. Even this does not give any certain guide as to the behaviour of such a petrol; in fact, it may be definitely misleading, as we shall see later. Further knowledge may effect changes, but at the moment the only true criterion as to the excellence of any given petrol, provided it passes all standard routine tests for purity, vapour, pressure, etc., is an empirical one, *i.e.*, running in a variable compression test engine so as to discover its highest useful compression ratio under certain conditions definitely laid down.

The viscosity of petrol or its substitutes is of some interest. According to Professor Brame, whose series of Howard lectures are very well worth study, Sorel obtained the following figures for the weight of liquid passed: (water at 15°C. being taken as 100).

| | Petrol. | Benzol. | Alcohol. |
|---|---|---|---|
| 0°C. | 100 | 60 | 22 |
| 30°C. | 116 | 116 | 45 |

The variation with different fuels is most marked and is unfortunately not in the desired direction. With Benzol and Alcohol nearly double the quantity was passed within working range temperatures.

The calorific value of fuels varies considerably as the following average values will show:—

Petrol: 19—20000 B.T.U. per lbs.
Alcohol: 11—12000 ,, ,, ,,
Benzol: 17—18000 ,, ,, ,,

As however fuel is purchased by the gallon the more suitable of the hydrocarbon fuels, *i.e.*, those composed mainly of naphthenes and aromatics and consequently of higher specific gravity, have an advantage viewed from the standpoint of B.T.U. per gallon, as the following figures of Ricardo will show:—

| Sp.G. | B.T.U. Per lb. | Per Gallon. |
|---|---|---|
| 0.704 | 19.250 | 135.500 |
| 0.727 | 19.120 | 137.000 |
| 0.760 | 18.890 | 143.500 |

or expressed more clearly let us take from the same source :—

A. A petrol mainly composed of paraffins.
B. A petrol mainly composed of naphthenes and aromatics.

| | Sp.G. | B.T.U. per lb. | B.T.U. per gall. | % Excess B.T.U. | H.U.C.R. | Total increase in efficiency. |
|---|---|---|---|---|---|---|
| A. | 0.705 | 19.130 | 134.866 | — | 4.6-1 | — |
| B. | 0.785 | 18.450 | 144.832 | 7.4% | 5.8-1 | 22% |

There are in existence in this country three B.E.S.A. specifications for petrol :—

A. Motor Spirit.
B. Aviation Spirit.
C. ,, ,,

The general characteristics are as follows :—

| I.B.P. | A. 20% over. | F.B.P. |
|---|---|---|
| 55°C. | 105°C. | 225°C. |

| Sp.G. | Boiling Range. | B. | Aromatic Content. | Toluene Equivalent. |
|---|---|---|---|---|
| 0.720 | 75°C. | 10% | | |
| 0.740 | 100°C. | 60% | 12—20% | 10% |
| | 140°C. | 95% | | |
| | | C. | | |
| 0.760 | 75°C. | 10% | 35% | 28% |
| 0.790 | 100°C. | 50% | | |
| | 150°C. | 90% | | |

The motor spirit specification is similar to the American standard specification, but in fact most of the brands marketed to-day are of much higher grade than the specification calls for. For example, although an end point of 225°C. is permissible, about 190°C. is found to be about the average. In America it is about 220°C., but certain recent figures give crankcase oil dilution as high as 30 per cent., so that high boiling fractions have considerable disadvantage unless great care is taken to guard against the obvious risk. Various tests both on the ground and in the air, many of which have been undertaken in America, some in the Altitude Chamber of the Bureau of Standards, clearly show the undesirability of having any high percentage of low boiling constituents in aviation spirit due to the possibility of the occurrence of gas locks in the petrol flow lines at altitudes. Difficulties were also experienced with excessive cooling when using a fuel of high latent heat of evaporation.

Having reviewed in quite a general way some of the characteristics desirable and otherwise to be found in various fuels, let us consider the individual products more closely.

### *Petroleum (Casing Head Spirit)*

The term "casing head gasoline," as might be expected, originated in America, as also did the industry of the recovery of petrol from natural gas and is of comparatively recent origin. Such gases often issue under pressure as high as 1,400 lbs., and may emanate from gas wells or pass with the crude from the wells. There are three different methods of extraction and the production of petrol from this source is enormous. The average yield is from two

to three Imperial gallons per 1,000 cubic feet. Yields, however, of over ten gallons have been obtained. The spirit produced is naturally largely composed of low boiling fractions consisting generally of hydrocarbons of the paraffin series. It is, however, useful from the point of view of blending. From the aeronautical standpoint this industry is of interest as helium occurs in certain natural gases (usually under two per cent.) and has been largely extracted for use in place of hydrogen in lighter-than-air craft.

The U.S. Bureau of Mines gives certain figures for the distillation of casing head spirit, showing :—I.B.P. 31°C., 50 per cent. over 61°C., F.B.P. 143°C.

### *Petroleum (Straight Run Spirit)*

The term " straight-run spirit " is used to clearly define the product which is produced during the ordinary process of the distillation of the crude oil from cracked spirit, about which we shall hear more further. The fact that there is such a variety in the crude oils found is also true of the spirits produced therefrom. It has, however, been remarked that leaving aside any form of doping, a spirit pertaining to the asphalt base class of oils will usually give the best results in an internal combustion engine. This means the use of a spirit of high specific gravity and opens up the desirability of serious consideration for aircraft purposes of the use of dopes with spirits of low specific gravity, with the consequent and all-important advantage of weight-saving. For the moment this is not possible as no such entirely satisfactory dope exists, but its discovery cannot be far distant.

Although a knowledge of the general chemical composition of any petrol is most essential, it does not necessarily, as has been remarked, give any certain value as to its suitability. The following figures obtained with that really invaluable asset the Ricardo single-cylinder variable compression engine, are of particular interest. In passing, it should be noted that this engine, quite the first of its kind, although many models have been built, has enabled more than any one other cause the characters of different fuels to be appreciated. The compression of this engine is variable, when running, between 3.7 to 1 and 8 to 1.

*Approximate composition* :

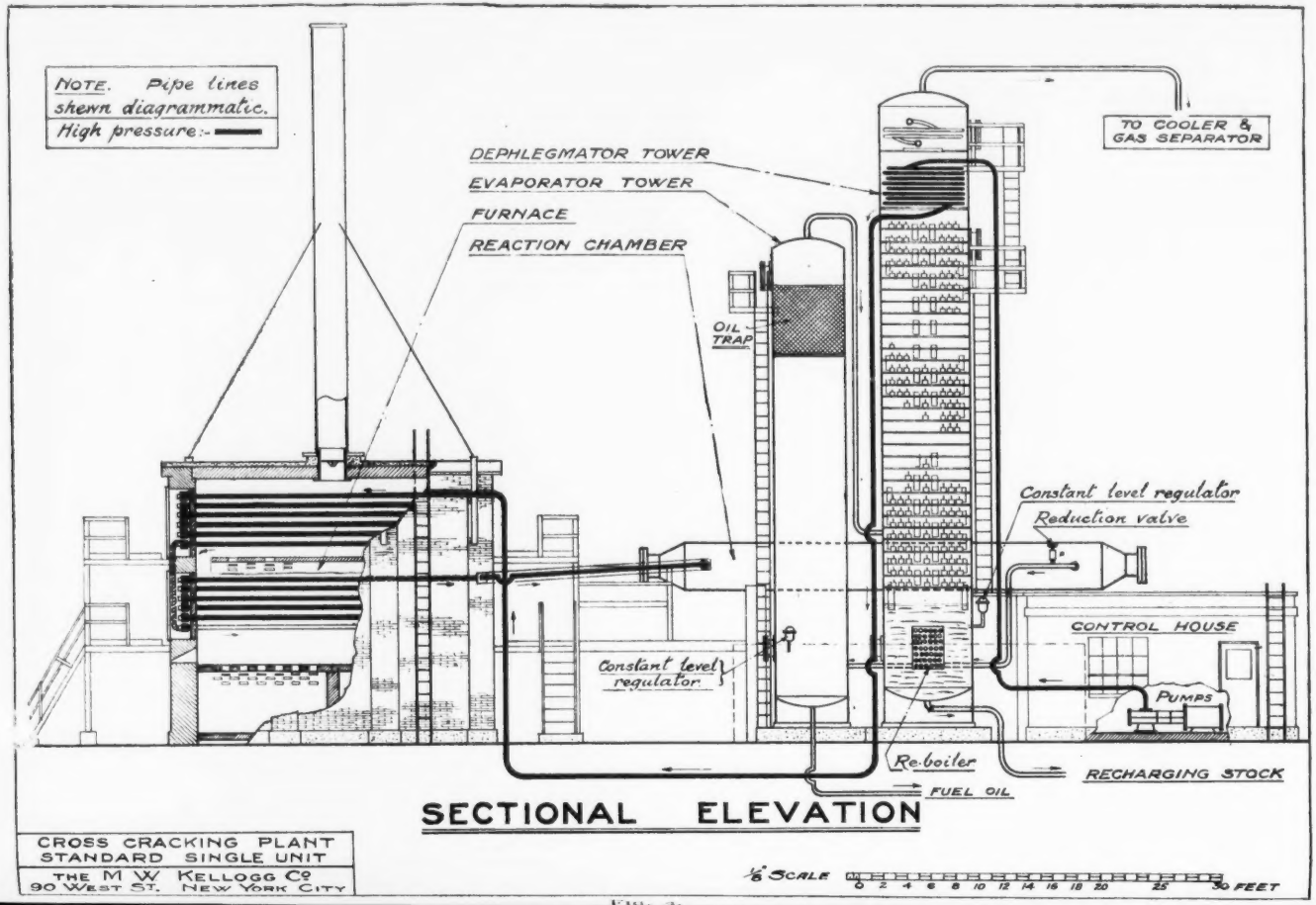
| Paraffins. | Naphthenes. | Aromatics. | H.U.C.R. | Consumption per B.H.P. Hour. |
|---|---|---|---|---|
| 62 | 23 | 15 | 5.7 | 0.435 pts. |
| 68 | 20 | 12 | 4.7 | 0.484 pts. |

The difference in H.U.C.R. between two fuels that are of the same approximate composition is strange and may be due to the fact that no accurate method is known of determining the naphthene content or to the fact that little or nothing is known of the composition of various paraffin hydrocarbons which may contain elements favourable to the promotion of detonation. If the compression ratio is low enough the efficiency of all hydrocarbon fuels is the same. The advantages to be obtained from employing the highest possible compression ratio are well emphasised in the example above.

Ricardo has shown that petrols have an H.U.C.R. lying between 4.2 to 1 and 6.0 to 1.

The indicated thermal efficiencies at various compressions are made clear by the following :—

| Compression Ratio. | Indicated Thermal Efficiency. | Air Cycle Efficiency. | Efficiency Relative to Air Cycle Efficiency. |
|---|---|---|---|
| 4.1 | 27.7 | 42.56 | 65.0 |
| 5.1 | 31.9 | 47.47 | 67.1 |
| 6.1 | 35.3 | 51.16 | 68.8 |
| 7.1 | 37.5 | 53.98 | 69.6 |


NOTE. Pipe lines shewn diagrammatic.
High pressure:-
DEPHLEGMATOR TOWER
EVAPORATOR TOWER
FURNACE
REACTION CHAMBER
TO COOLER & GAS SEPARATOR
OIL TRAP
Constant level regulator
Reduction valve
CONTROL HOUSE
PUMPS
Constant level regulator
Re-boiler
RECHARGING STOCK
FUEL OIL
SECTIONAL ELEVATION
CROSS CRACKING PLANT
STANDARD SINGLE UNIT
THE M W KELLOGG Co
90 WEST ST. NEW YORK CITY
1/8 SCALE
0 2 4 6 8 10 12 14 16 18 20 25 30 FEET

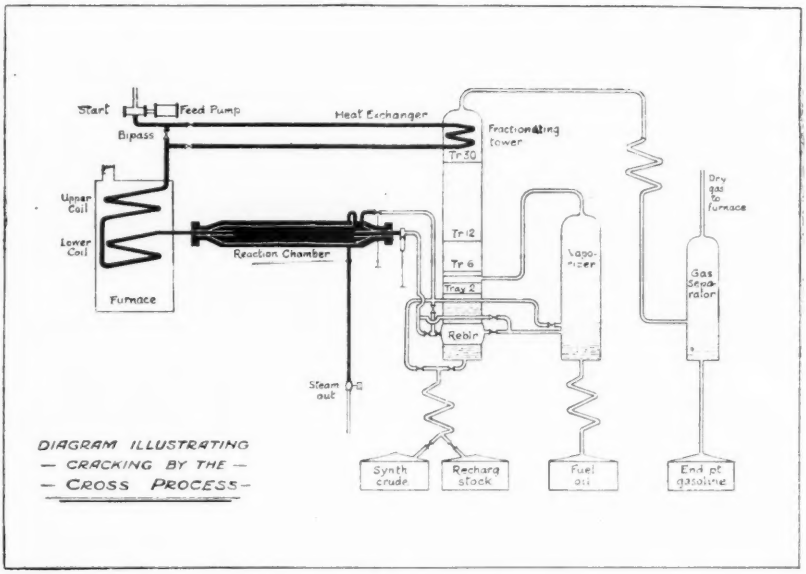



FIG. 4.

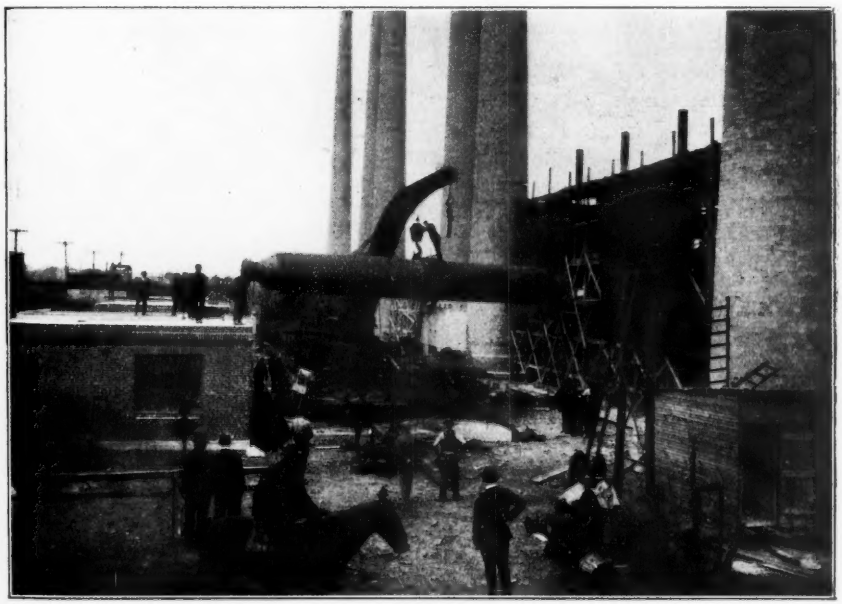


FIG. 5.
*Cross Cracking Units, Point Breeze.*
*Erection of Reaction Chambers.*

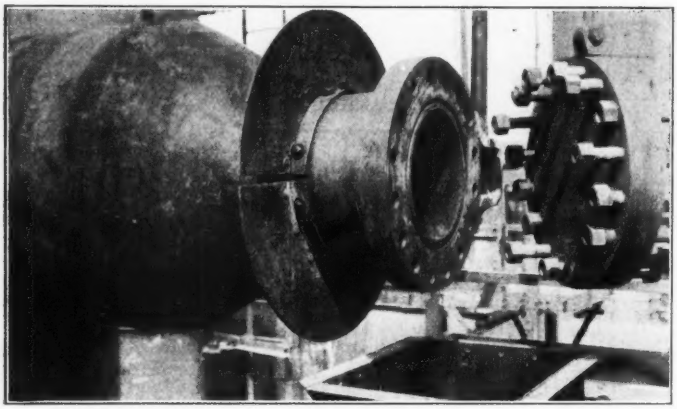


FIG. 6.
*Reaction Chambers, showing door open for cleaning.*

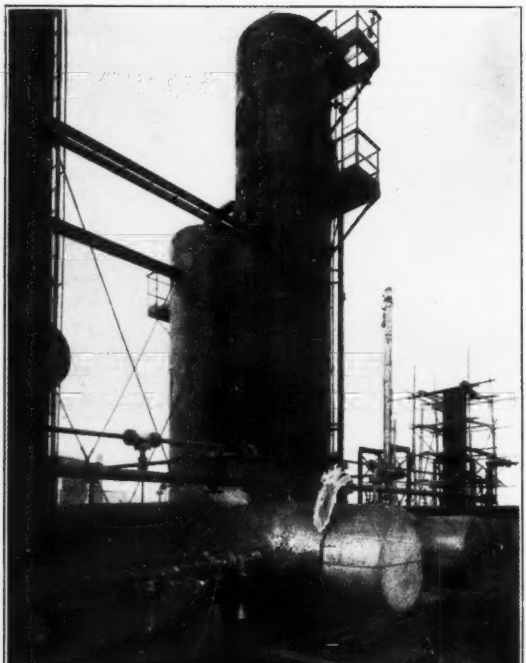


FIG. 7.
*Bubble and Evaporator Tower, showing Reaction Chambers in foreground.*

### *Petroleum (Cracked Spirit)*

The phenomenon of cracking was accidentally noticed in America some sixty-five years ago, although it was used by James Young in Scottish shale works for increasing kerosene yield before this. The object of cracking is the production of low boiling products within the boiling range of ordinary petrols from those products such as kerosene or gas oil and fuel oil or other residuals which ordinarily contain only fractions of considerably higher boiling range. In other words, the aim is to produce a greater quantity of petrol from the crude oil than the ordinary methods of distillation will yield. Young, whom we have

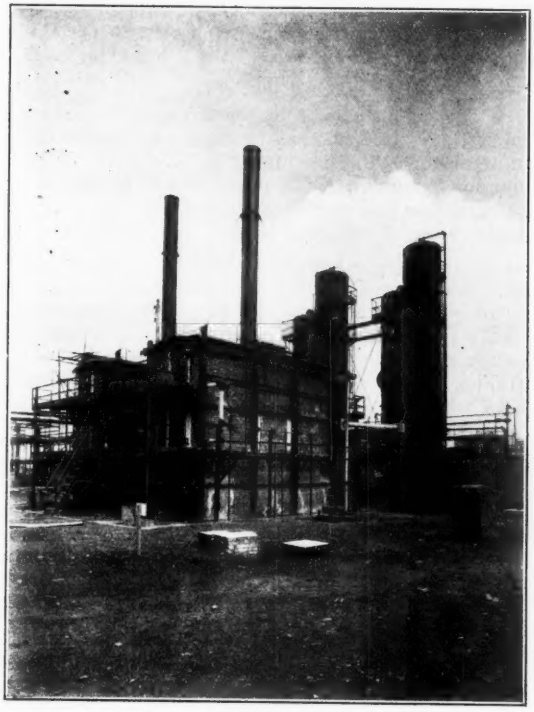


FIG. 8.

*Two* 1,000 *bbl.* "*Cross*" *Cracking Units* (*one double unit*).

already mentioned, was one of the earliest investigators and was later followed by Redwood and Dewar. The work of the British pioneers in this field, the two latter in particular, has virtually founded the basis of the cracking developments that have made such enormous strides in the U.S.A. Economic forces have brought about the fact that the real developments on the full scale have occurred on the other side of the Atlantic and we find that American plants or plants of American design are being put up here, and in fact in Europe.

By far the most generally adopted process to-day is the Cross, that functions substantially in the liquid phase, and being very flexible is able to crack a wide range of distillates and is now being developed successfully to crack residuals. The Dubbs process is also used, as have been many others to a limited extent.

The theoretical side of this complex subject has so far been little explored, but a certain amount of investigation on cracked spirit has been carried out in this country in which the writer has been greatly interested.

No apology is really needed for dealing with this subject somewhat fully, as it is little understood over here and is destined to play a large part in increasing the supplies of petrol. In America almost 30 to 40 per cent. of the petrol produced is cracked, and in this country a greater percentage of cracked spirit generally blended with straight-run is marketed than many imagine. This point is mentioned as there still exists, admittedly with some reason, a prejudice against such a spirit. This is largely founded on æsthetic considerations of smell, but the difficulty of treating cracked products satisfactorily so as to produce a stable spirit that will not polymerise has given rise to certain legitimate complaints in the past. A greater knowledge of the subject has enabled this difficulty to be overcome.

Even to-day it is possible to see that cracked spirit may one day be at a premium as compared to straight-run; in fact, this has occurred in America, as there is a lot of evidence to show that the H.U.C.R. of the former from a given crude is superior to the latter. A great deal of further research is required on the influence of pressure and temperature and the time given for the cracking reaction over a wide range of cracking stocks.

The fact that those hydrocarbons most desired from an efficiency standpoint are the most stable under conditions of high temperature, *i.e.*, the aromatics, is fortunate and is taken advantage of. At such temperatures it is known that particular reactions will give rise to the formation of aromatic compounds. The development of such plants as are in use to-day has proved a laborious and expensive undertaking, particularly in the case of the Cross process, where pressure as high as 700 to 800 lbs./sq. in. are employed with an oil temperature of approximately 552°C.

The treatment of the product itself as has been mentioned has been the cause of some difficulty now generally overcome. The presence of a fairly high quantity of unsaturates is found in cracked spirits. The diolefines are generally unstable and give rise to polymerisation and the formation of undesirable gummy residues, and these must be removed in refining. This is not an easy matter, as in removing these it is easy to remove the olefines, which are desirable bodies to retain and in so far as can be known tend to raise the H.U.C.R.

Some twelve years ago the writer made a series of full-scale bench and flight tests with a spirit cracked from a Texas gas oil. The results were encouraging, as although no means existed of accurate observations, the engine in question ran more smoothly than on the standard spirit, the cause of which would be quite clear to us to-day, although then somewhat obscure. Nevertheless, we still find that, for the moment at least, the B.E.S.A. Specifications B and C exclude cracked spirit.

Some results obtained with spirit *cracked from Russian kerosene* in the Cross plant belonging to the Medway Oil and Storage Co., Isle of Grain, will be of interest. Certain other spirits have been tested to obtain comparative results. The first tests were carried out by Mr. Ricardo at the writer's request. The spirit was unblended, being merely the acid-treated product direct from the bubble towers of the Cross plant of the Medway Oil and Storage Co. (known as Power petrol). The H.U.C.R. of the two samples submitted was found to be 5.78 and 5.79 respectively.

Further tests were made on the Ricardo V.C. engine to determine the minimum fuel consumption obtainable as compared with that of an A aromatic free petrol. The compression ratio for these tests was fixed at 4.5 to 1 and

the results are shown clearly in the accompanying graph. The minimum fuel consumption in pints per i.h.p. hours were:—

| | |
|---|---|
| Power petrol ... ... ... | ·458 |
| Aromatic free petrol ... ... | ·475 |

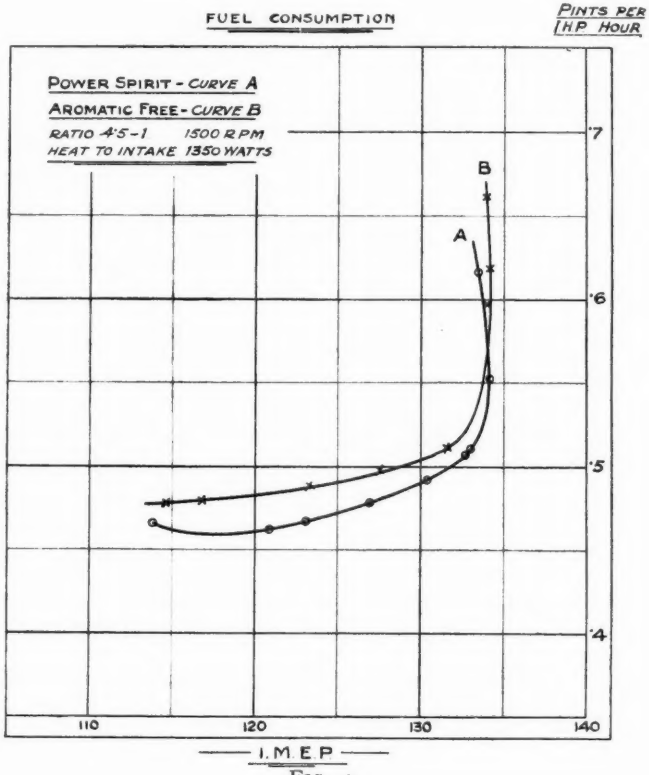



FIG. 9.

The maximum power with each is equal to within less than half of one per cent. The cracked spirit was found to give excellent all-round results, the only comment being made in regard to its low effective volatility, 14°C. being the temperature in the induction pipe as compared with 10°C. for the aromatic free petrol. As, however, it is general practice to blend petrol to bring this to any required specification, the difficulty would be overcome.

It must be clearly understood that the cracked spirit referred to in this paper under its proprietary name of " Power " Petrol is in every case the product of cracking a kerosene derived from the South Russian Oilfields. It must not, therefore, be inferred that all cracked spirits exhibit similar characteristics or that " Power " petrol is always produced by the cracking of Russian kerosene.

The results of certain investigations carried out at the R.A.E. on cracked spirit have clearly shown that there was no deposition of crystals at temperatures to −100°C. nor was any corrosive or gummy action to be expected. This very thorough investigation should serve to dispel many of the prevalent ideas as to the general unsuitability of cracked spirits.

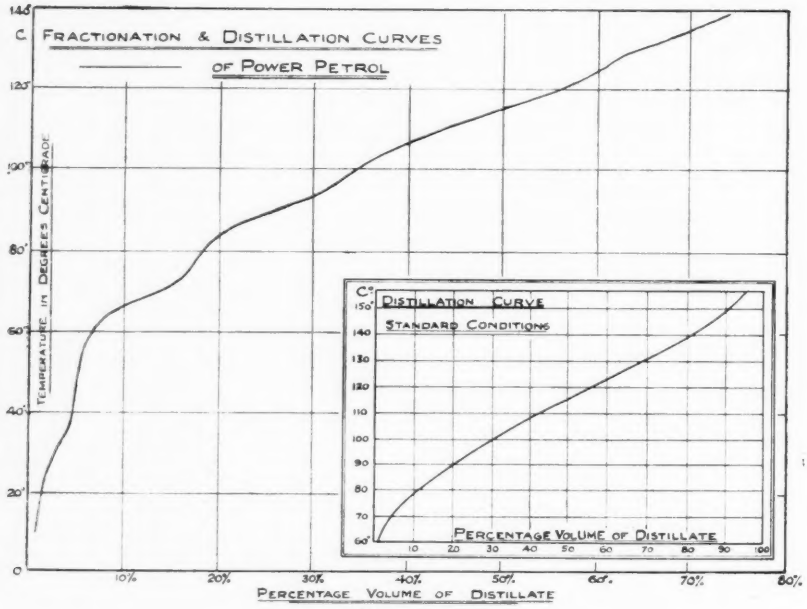



FIG. 10.

Subsequently further tests were made in the A.M. Laboratory at South Kensington with the idea of not only investigating cracked petrols, but of endeavouring to ascertain the appreciation in H.U.C.R. as a result of cracking. Tests were carried out on a Ricardo engine at 1,500 r.p.m. with a spark setting of 30 advance and no heat input to carburettor.

| Fuel. | B.M.E.P. | H.U.C.R. |
|---|---|---|
| Baku Kerosene ... ... ... ... | 123 | 4·7 |
| Power Petrol unrefined ... ... ... | 141 | 6.1 |
| Power Petrol refined ... ... ... ... | 143 | 6.1 |
| Baku Straight-run ... ... ... ... | 140 | 5.8 |
| B.P. No. 1 ... ... ... ... ... | 128 | 4.90 |
| Shell Aviation ... ... ... ... ... | 137 | 5·55 |

Contrary to expectation, the refined Power petrol gave slightly superior results to the unrefined. A repetition of these tests confirmed this result. The ordinary H.U.C.R. for the average kerosene would be about 3.8 to 1 to 4.0 to 1, and the high value of the Baku products may be accounted for by the fact that South Russian crudes are notably rich in naphthenes, thus producing an excellent kerosene for I.C. engines, but an unsuitable lamp oil. The values for B.P. and Shell were obtained at the same time for purposes of comparison.

Further tests were carried out by Messrs. Armstrong-Siddeley Motors (Capt. Briggs), Messrs. H. M. Hobson, Ltd. (Major Searight and Capt. Dodson), and Messrs. The Bristol Aeroplane Co. (Mr. Fedden), all bearing out the tests already referred to. Results of test showed that Power petrol was usable in an ordinary four-cylinder W.C. engine with a compression ratio of 6 to 1, while Shell No. 1 was not, due to detonation. The consumption of the former was also better.

In another test Power petrol was tested against a standard Shell 80/20 aviation mixture and no great differences were noticed, except at one speed

when pinking occurred with the former. The attached diagram relates to the latter tests on an air-cooled single-cylinder (Mark VI. Jupiter) with a compression ratio of 5.3 to 1 developing 53 h.p. at 1,700 r.p.m. The cylinder temperature curves in the same figure are also interesting.

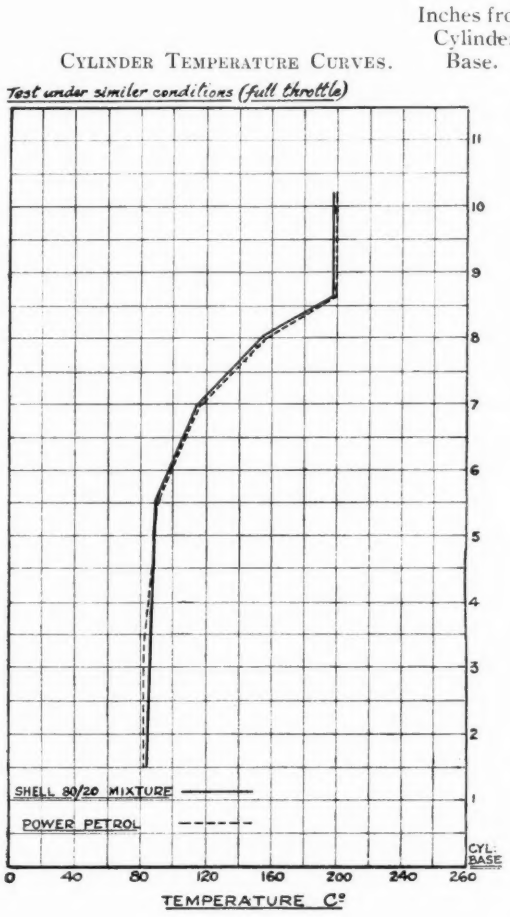



FIG. 11.

## *Shale Oil*

The fact that oil shales will be called upon in the future to provide a source of fuel supply is in itself sufficient reason for touching on this matter. The origin of oil shales provides material for a great deal of speculation, probably no one explanation stands good. Craig, for example, regards sources of oil shale supply as the relics of former oil fields. A notable characteristic is the high percentage of unsaturates largely due to the low hydrogen content of the kerogen. This introduces one of the chief difficulties, *i.e.*, that of refining. The following are the particulars of a petrol from Scottish oil shale :

Sp.Gr. 0.728
I.B.P 43°C.
F.B.P. 168°C.
Distilling to 75°C. = 7%
,, ,, 100°C. = 44%
,, ,, 125°C. = 81%
,, ,, 150°C. = 95%

FUEL CURVES COMPARING POWER PETROL WITH SHELL 80/20 MIXTURE.

Sp. G. Shell 0.760. Jupiter VI. Single cylinder. Lbs. per B.H.P.
Sp. G. Power 0.754. C. Ratio 5.3 to 1. R.P.M. 1700. per Hour.

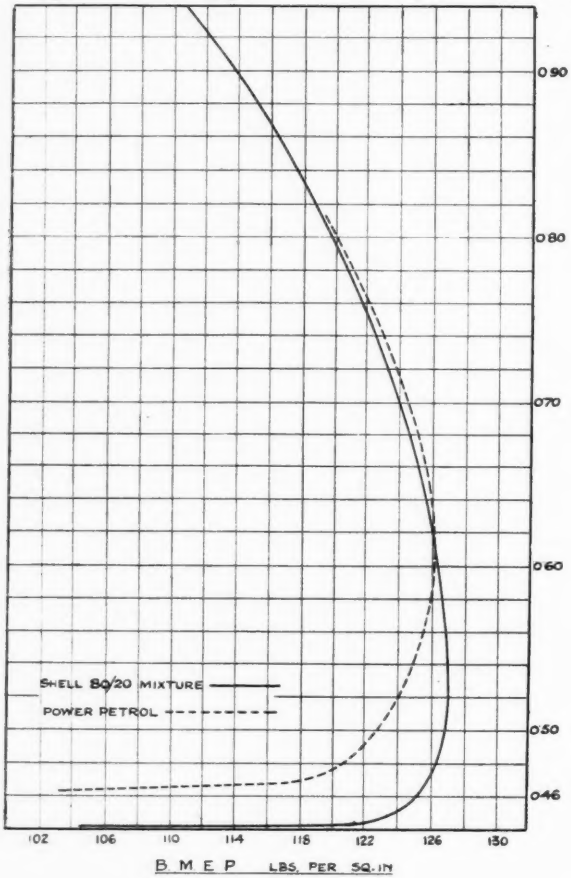



FIG. 12.

### *Coal Products—Benzol*

The most generally known and widely used fuel for I.C. engines obtained from coal, in particular gas works and coke ovens, is benzol. Being composed

principally of aromatic hydrocarbons in the main, benzene, toluene and xylene being the essential constituents, its use in conjunction with ordinary petroleum products is as wide as supplies will allow. Endeavour is being made to augment the supplies of benzol by the supplanting of out-of-date equipment and by the introduction of new methods of absorption employing mediums such as silica gel or aluminium silicate.

Apart from the fact that it is too valuable for use in its undiluted state, its high freezing point ($-14$°C.) would rule it out for aviation purposes. Even so the use of petrol/benzol mixtures, now almost universal, does not necessarily mean that the freezing trouble is completely overcome. Whereas benzol may freeze at about minus 15°C., an 80/20 per cent. petrol/benzol mixture will freeze at about minus 45°C. and 50/50 about minus 20°C. It is therefore evident that military aircraft may not infrequently be flying at such a height as to meet with a temperature which may frequently be below minus 45°C. The results of tests, however, so far carried out show no serious effects, at least for the time an aircraft would normally remain at such altitude. Temperature lag plus the turbulence are both particularly responsible for this. As has already been mentioned, benzol is to-day nearly always blended with any spirit used for aviation as it checks detonation and thus permits of the more efficient use of the fuel. There was a time when the specification issued by the Air Ministry was such as to produce a fuel of low aromatic content. At this time the whole problem of fuels was so little known or appreciated that supplies of benzol were frequently not available, abroad in particular. In consequence no inconsiderable number of engines of a certain type were ruined, experiencing major failures as a result of heavy detonation and the cumulative bad effects arising therefrom.

The B.E.S.A. motor benzol specification is as follows:—

Spec. Gravity.—0.870 to 0.885 at 15.5°C.
Distillation.—60% over at 90°C. 75% over at 100°C. 90% over at 120°C. Dry at 125°C.
Residue.—Not to exceed 0.01%.
Sulphur.—Not to exceed 0.4%.
Freezing Point.—Not higher than $-14$°C.

The H.U.C.R. of the principal aromatic hydrocarbons mentioned before is practically the same in all cases, *i.e.*, circa 7.0 to 1. According to the investigations of Ricardo toluene was found to have the best anti-detonating effects, followed by xylene and benzene. These tests led to the adoption of the term toluene value now generally employed and to be found in the B.E.S.A. aviation spirit specification already referred to. Toluene as the standard is given a value of 100. In the B.E.S.A. specification 150 parts of benzene and 120 parts of xylene are taken as the equivalent of 100 parts of toluene.

### *Naphthalene*

The development of naphthalene as a source of fuel supply has received but little attention in this country, but a great deal in Germany owing to stress of circumstances imposed by the war. Dr. Dunstan gives the production figures for this country of circa 50,000 tons per annum, which could, of course, be greatly increased. The virgin product is solid, melting at 80°C. The hydrogenation process developed by Professor Schroeter has resulted in the production of two compounds, tetralin and decalin, with an intermediate product known as tetralin-extra. The former product is partially saturated, the latter (decalin) completely so. A very comprehensive investigation was carried out by Sir Frederick Nathan. Satisfactory results were obtained when using not more than 50 per cent. of tetralin mixed with petrol. In cases where more than 50 per cent. of tetralin has been employed starting and other difficulties have been met with, but it is

possible that these might be overcome by alterations to the engine. The influence of tetralin on the H.U.C.R. is distinctly beneficial. In addition to a petrol-tetralin mixture mixtures with benzol and alcohol have been employed with success.

### *Low Temperature Carbonisation*

The numerous tests that have been undertaken in regard to the low temperature carbonisation of coal and the great interest that has arisen round this whole question led the writer to procure a sample of the light fuel produced. The sample was obtained from the experimental plant of the Low Temperature Carbonisation Co., Ltd., at Barnsley. The tests were undertaken at the A.M. Laboratory at South Kensington, by courtesy of the Director of Scientific Research, who has been keenly alive to the necessity of investigating potential sources of fuel supply. The H.U.C.R. of the sample was found to be 6.5 to 1 as against 5.7 to 1 for Shell aviation spirit; the former value would have been higher but for slight pre-ignition occurring.

The average light fuel yield from this process is stated to be in the neighbourhood of :—

From the residual oil 1.0 to 1.6 gallons per ton of coal carbonised.
From the gas 2.0 to 3.8 gallons per ton of coal carbonised.

The distillation of a sample showed a high dissolved gas content, as although boiling commenced at 30°C. the first drop did not condense until a temperature of 44°C. was reached.

I.B.P. 44°C.
70% over 100°C.
F.B.P. 144°C.

This fuel is considered most suitable for aviation purposes, the mean volatility and H.U.C.R. being high. It is remarked that Shell aviation spirit would require the addition of 40 per cent. of benzene to give equivalent results.

### *Hydrogenation (Bergius Process)*

A new field is being opened up by Bergius in Germany, who claims that about 65 per cent. by weight of certain coals can be converted into oil, 25 per cent. of this being available as a light fuel. The process is in the advanced experimental stage, but it would appear that the cost of the plant will be high owing to the great pressure employed. Furthermore, the cost of the hydrogen required will be no small matter. As a ton of coal has to be burnt for every ton of throughput the actual yield of light fuel for coal consumed would be in the neighbourhood of 15 gallons per ton. The recent report to the Minister of Agriculture, to which reference has already been made, states: "This is the only process involving the direct treatment of coal from which it would be possible to produce all the supplies of oil needed in this country, but on the question of cost it is not possible even to venture an opinion." It is estimated that four or five years will have to elapse before any commercial data is available. The work of Bergius and others along somewhat similar lines is of great importance, as, if successful, coal fields will become potential oil fields.

### *Other By-Products*

The production of alcohol from coal which has already been referred to will be dealt with further, as also the production of dopes.

### *Alcohol*

The great advantage of alcohol as a fuel lies in the fact that it will stand a greater H.U.C.R., viz., 7.5 to 1, than the best of the hydrocarbons. The water

content of commercial alcohol presents at once an advantage and a difficulty. The advantage is that it allows high M.E.Ps. and good volumetric efficiencies to be obtained, although viewed from the weight-power ratio of the fuel this advantage may be too dearly bought. The disadvantage is that which arises in mixing alcohol and hydrocarbons. The high latent heat of evaporation of alcohol is another of the advantages, as Ricardo has pointed out that this fact explains to a larger extent the excellent anti-detonating quality of this fuel. In general some form of blending has to be undertaken due to the very low vapour pressure, so low in fact is it that a temperature of near 30°C. is required to form an explosive mixture. Some of the advantages have been mentioned, but there is present at the moment the serious question of continued supply at reasonable cost. Tests carried out show that higher thermal efficiencies can be obtained than with petrol or benzol; a figure of some 2½ per cent. can be taken. These higher thermal efficiencies can be obtained in high or low compression engines in comparison with petrol or benzol. The lengthy series of investigations undertaken by Mr. Ricardo and set out in that very useful report of the Empire Motor Fuels Committee are very encouraging. It is remarked that the running of the test engine at all times and under all conditions, even at a compression ratio of 7.0 to 1 corresponding to an approximate compression pressure of 185lbs. to the square inch, was smoother and sweeter than on petrol.

Ethyl alcohol of 90-99 volume per cent. was tested, and results show the beneficial effects in regard to increased power output obtained at high compression ratios with greater percentages of water; at lower compressions a slight decrease is to be observed. The following illustration makes this clear:—

| Compression Ratio. | 99%. | 90% |
|---|---|---|
| 3.8 to 1 | 27.5 | 26.6 |
| 5.0 to 1 | 32.2 | 31.6 |

At a compression ratio of 6.0 to 1 there is no fall in power as between 90 and 99 volume per cent. alcohol. To gain in full the advantages of higher thermal efficiency obtainable from alcohol higher compressions and better distribution would have to be provided. The report to the Minister of Agriculture, quoted before, sets this matter down very succinctly as hereunder:—

FUEL CONSUMPTION RATIO.

| Ethyl Alcohol. 95 volume per cent. | Alcohol/Petrol. | Alcohol/Benzol. |
|---|---|---|
| Modifications to existing engines—carburettor adjustments ... ... ... ... ... | 1.8 | 1.9 |
| Raising compression to maximum H.U.C.R. for average petrol ... ... ... ... ... | 1.5 | 1.7 |
| Raising compression to 70.1 or so ... ... | 1.1/1.4 | 1.6 |

Dr. Ormandy, who has devoted a great deal of attention to the possibilities of alcohol as a fuel, recently made an examination of a number of engines on the Continent that had been running on alcohol for periods up to eight years. The results observed were most satisfactory, no signs of corrosion being exhibited.

The use to which it is considered alcohol will be put will be in forming mixtures of various fuels such as alcohol/ether, alcohol/petrol, alcohol/benzol, or alcohol/benzol/petrol. As has been mentioned before, the water content of commercial alcohol, containing as a general rule not less than 5 per cent., proves a difficulty. When it is considered that a petrol/alcohol mixture of 100 volumes of the former to 10 of the latter will be thrown out of solution with less than 2 per cent. of water in the alcohol the difficulties to be overcome will be realised. Investigations have been undertaken in an endeavour to discover compounds that will ensure or at least increase stability such as butyl and amyl alcohol. Furthermore, the possibilities of producing anhydrous alcohol economically is

being gone into, and rumours are current that such results are being achieved on the Continent. Even this latter method is no guarantee of permanency, due to the well-known hygroscopic character of alcohol. The fact, however, that the admixture of alcohol with petrol will give practically double the efficiency of that of benzol added to any given petrol makes the overcoming of these problems a matter well worthy of attention.

The difficulties of mixing alcohol and petrol are considerable and it has always appeared curious why no really extended test has been made by the Air Ministry with engines modified to operate on the "bi-fuel" system. The early tests showed great promise and the strong recommendations of the Aeronautical Research Committee would, one would have imagined, been productive of a full-scale trial of the magnitude that was suggested.

In America, as in this country, alcohol mixtures have been used with success. The navy department have experimented with a mixture of petrol/alcohol 70-30 and found that very small quantities of water (0.5 per cent.) raise the point of turbidity to $-10°C$. from approximately $-50°C$.

Alcohol/petrol/benzol mixtures are sold in this country, Discol being probably the best known. Natalite, an alcohol/ether mixture 60-40, has been imported in small quantities from South Africa where it is extensively used.

### *Dopes*

Having now in a general way examined various light fuels we shall pass on to consider the possibility of the addition of other substances to petrol in particular with a view to its utilisation in a more efficient manner. The effects of benzol and alcohol in achieving such a result has been shown, and it is clear that fairly considerable amounts of 10 per cent. or more must be employed. There are however a large number of substances generally classified as "dopes," which when used in minute quantities have a remarkable effect in raising the H.U.C.R. of the fuel to which they are added.

Further investigations are continuing both in this country and America, and a wide range of compounds possessing in some cases detonating as well as anti-detonating effects has been brought to light. The credit for opening up this particular line of research must be given to Messrs. Midgley and Boyd in America. Of the various organo metal compounds "lead tetra ethyl" is probably the most remarkable. The investigations carried out by these two have confirmed in many respects the work of Ricardo, except that they consider the aromatic hydrocarbon xylene more efficient in its anti-detonating properties than toluene. It may, however, be noted that these results of Messrs. Midgley and Boyd are not confirmed by other investigators in this country.

Messrs. Midgley and Boyd have used a xylidine/kerosene fuel as a standard to work from. The fact that the aromatic amines are very efficient anti-detonators, more so than hydrocarbons, will be referred to later on. A single cylinder air-cooled engine was employed for these tests, and an endeavour in an ingenious manner has been made to measure the amount and intensity of detonation as opposed to Ricardo's oral observations of this puzzling phenomenon. The Midgley bouncing-pin apparatus consists of a small piston held flush with the inner surface of the cylinder head by a strong spring. Above this piston rests a steel pin which is thrown clear when detonation takes place, thus closing a circuit and causing the formation of gas, a water electrolysis apparatus being in the circuit, the volume of which is assumed to measure the amount of detonation.

The result of these early experiments led to the use in America of lead tetra ethyl as a dope. When used alone, this compound was found to have deleterious effects on the lubricant and to deposit salts of lead on the sparking plugs, valves, etc. In an endeavour to cure this trouble small quantities of ethylene dibromide

were added so as to cause the lead to be converted into lead bromide and blown out through the exhaust ports. The mixture thus formed is known as ethyl fluid and is recommended for use in the ratio of 5 c.c. per gallon. This consists of 3 c.c. of the lead tetra ethyl and 2 c.c. of the halogen compound. Lead tetra ethyl is by itself intensely poisonous, and due to the occurrence of certain fatalities in its manufacture its use became greatly, although possibly only temporarily, restricted in America. When mixed in the small quantities mentioned with petrol, no ill effects need be feared, nor is the already poisonous nature of the exhaust gas made more virulent.

From tests made over here it seems doubtful as to whether the addition of the halogen compound has had the desired effect to the fullest extent. According to tests recently made on a Napier " Lion " at 80 per cent. full power

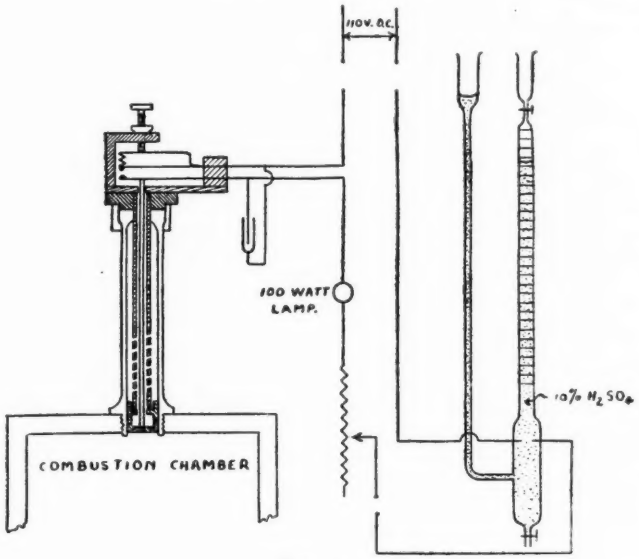



FIG. 13.
*Midgley's Bouncing Pin Apparatus.*

on the recommended quantity for 100 hours, troubles were experienced due to the depositing of lead salts on the sparking plugs giving rise to electrical leakages and causing permanent damage to the mica insulators. According to the same source the use of the recommended quantity, it was calculated, would permit an increase of compression ratio of about 10 per cent. The addition, however, of a quarter of 1 per cent. would enable the compression to be raised 40 per cent., a corresponding gain in power of 14 per cent. on the same fuel consumption. In early tests made over here some years ago, it was thought that there was no gain to be achieved in the use of more than 5 c.c. of lead tetra ethyl per gallon, but subsequent tests carried out by Professor Callendar, Captain King and Flight-Lieutenant Sims, whose work on these and similar problems has been invaluable, do not support this theory. At the same time it is quite likely that the use of a greater quantity may cause a considerable increase of the troubles already met with. Colour is given to this by the fact that the Ethyl Gas Corporation of America recommend the use of 5 c.c. of ethyl fluid per gallon as being suitable for aero engines with a compression ratio of

5.5 to 1, and no mention, except indirectly, is made of using larger quantities. It appears that in addition of lead ethide up to 9 c.c. per gallon the increase in H.U.C.R. is strictly proportionate to the fuel. After this the rate of increase is slower, as may be seen from the accompanying curves.

Tests of ethyl fluid have appeared to show that the halogen compound has a measurably beneficial effect on the H.U.C.R. which is somewhat unexpected. In any event comparisons between lead ethide and ethyl fluid are interesting. The fact, however, that ethyl fluid appears to give a different result, may be due to the presence of a greater quantity than 60 per cent. of lead ethide in its composition.

Another point of interest that has come to light is that the H.U.C.R. that can be obtained from a definite quantity of ethyl fluid, say 10 c.c. per gallon, appears to bear no particular relationship to the original value of the particular fuel, as the following tests will show :—

| Fuel. | H.U.C.R. of Fuel Alone. | H.U.C.R. of Fuel Plus 10 c.c. Ethyl Fluid. |
|---|---|---|
| " Power " ... ... ... | 5.8 | 7.3 |
| Shell " Aviation " ... ... ... | 5.8 | 7.3 |
| Shell No. 1 ... ... ... ... | 5.5 | 7.0 |
| Pratt's No. 1 ... ... ... ... | 5.4 | 6.8 |
| Bluebird No. 1 ... ... ... | 5.2 | 6.6 |

Before turning to dopes derived from organic substances, it is first necessary to consider the effects of other metallic compounds, in particular metallic sols. Considerable difficulty was experienced in an endeavour to make tests on compounds from aryl and other derivatives of copper, iron, etc. Eventually a number of tests were carried out, but the results obtained were poor and in some cases negative.

There are, however, two other compounds which are worthy of consideration, but whether they possess advantages over lead tetra ethyl is a matter for further tests. Flight-Lieut. Sims, in one of the many admirable contributions on this subject, very rightly wishes to focus attention on the use of a metallic dope containing a minimum weight of metal for a given effect, irrespective of the weight or volume of the compound itself. We have already some indication of the disadvantages of the deposit of lead salts when using lead tetra ethyl, and if any other compound is available giving approximately the same results in raising the H.U.C.R. and having a smaller quantity of metal in its composition, it will probably possess distinct advantages, always provided the metal deposited, although less in quantity, is not more deleterious in its cumulative effects. The following table brings this point out very clearly and shows that on this basis iron-penta-carbonyl is the best of the organo-metallic dopes.

| Compounds. | Weight of metal per litre of petrol. Grammes. | Weight of compound per litre of petrol. Grammes. | H.U.C.R. | % increase in H.U.C.R. |
|---|---|---|---|---|
| Petrol ... ... ... | 0 | 0 | 4.6 | 0 |
| Petrol—Lead tetra-ethyl ... | 2.0 | 3.2 | 6.45 | 40 |
| Petrol—Nickel tetra-carbonyl | 2.0 | 5.8 | 6.8 | 48 |
| Petrol—Iron penta-carbonyl | 2.0 | 7.2 | 7.41 | 61 |

### *Metallic Sols*

The recent investigations of metallic compounds mentioned in the last section would appear to show that on heating they decompose, yielding the metal in colloidal form. As a result of this, tests have been undertaken with fuels to which have been added the colloidal sols of iron, lead, nickel and other metals. These tests have shown that such substances are, speaking generally, just as effective as the organo-metallic compounds and in some cases slightly more so.

They seem to support also the contention that it is the metal alone which is the active agent in suppressing detonation. It does not seem likely that these metallic sols can be used except for purposes of experiment, owing to difficulties in production and their instability. Investigations, however, may lead to the discovery and test of other substances not suffering from these disadvantages. Some of the results are set out in the following table :—

| Substances. | Remarks. | Increase of H.U.C.R. |
|---|---|---|
| Iron sols ... ... | From iron carbonyl | 2 grammes metal/litre = 61 per cent. increase. |
| Colloidal nickel ... | Black sol stabilised in benzene | 0.34 grammes metal/litre = 41.5 per cent. increase. |
| Colloidal gold and gold oleate ... | Gold alloyed sols decompose rapidly | 1.2 grammes metal/litre = 1.8 decrease. |
| Colloidal carbon ... | Dark brown sol | Nil. |

Other results have been referred to previously, and only a few of the many tests made are quoted. A large variety of metallic sols have been tested and shown to have in certain cases a slight negative and in other cases a slight positive or neutral effect.

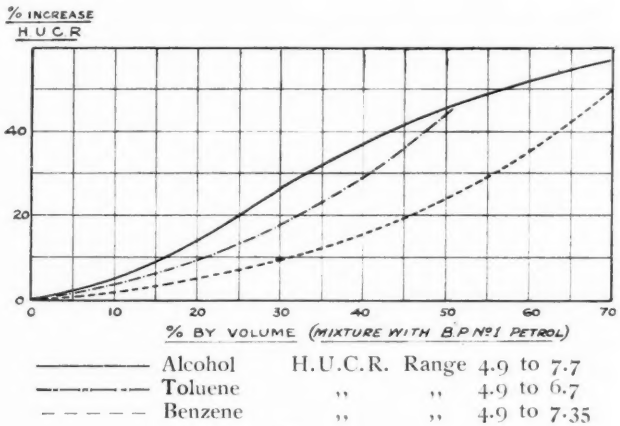



FIG. 14.

### *Organic Compounds*

We come again now to the consideration of certain organic compounds which will in the main probably not have the same deleterious effects as the metallic dopes, although of course larger quantities are required. The effects of substances such as alcohol and benzol have been already discussed and it is proposed to confine remarks mainly to the nitrogen compounds as it is believed that they offer a very profitable field of further research.

### *Nitrogen Compounds*

The aromatic amines are approximately ten times as efficient as toluene as an anti-detonating substance. A number of these such as toluidine, xylidine, etc., being of course benzene derivatives, may be difficult to obtain in the quantities required. The effect of the addition of various percentages of these anti-detonating substances to petrol has been shown before, but some further figures are given below as being interesting in that they indicate that in the

higher concentrations toluene is superior to alcohol, whilst in the lower these conditions are reversed :—

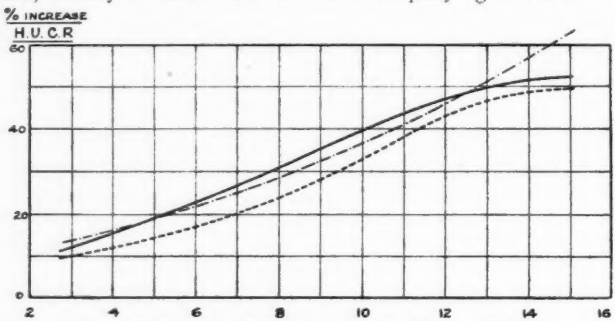
| Substances. | Percentage increase of H.U.C.R. with 75/25 mixture. | Percentage increase of H.U.C.R. with 50/50 mixture. |
|---|---|---|
| Alcohol ... ... ... | 13.7 | 42.8 |
| Toluene ... ... ... | 10.7 | 44.1 |
| Benzene ... ... ... | 4.7 | 24.0 |

### *Toluidine Group*

The three varieties of this substance were tried separately and as mixtures. Comparisons were somewhat limited by the fact that the para variety would dissolve to the extent of only six per cent. by weight. At high concentrations m/toluidine proved to be superior. It would not appear desirable to use concentrations greater than 15 per cent. In this connection tests were recently made at the Royal Aircraft Establishment on a sample concentration of this strength, and it was found that the fuel separated into two layers on cooling below 0°C. The deposition of tarry substances in the engine was also feared; for this reason further full-scale tests were delayed. Further tests are now being undertaken with a view to overcoming these difficulties.

### *Xylidine Group*

The results were somewhat similar to those obtained with toluidine; the admixture of more than six per cent. of the para variety, although not impossible, had to be specially dealt with. The m/xylidine proved the most desirable of this group. During one of the tests it was found that with a 15 per cent. m/xylidine concentration and at a compression ratio of 7.9 to 1, the engine ran steadily on compression ignition without decrease of power. Xylidine itself does not necessarily give maximum results with 15 per cent. concentration as does toluidine, as may be observed from the accompanying curves :




% Additions by Volume to B.P. No. 1 Petrol.

——— Mono Methyl Aniline.
—·—·— Xylidine (M).
– – – – – Toluidine (M).

FIG. 15.

The writer, when in Athens for the Greek Government at the beginning of this year, was asked to test the first aeroplane and seaplane built in Greece at the Naval Aircraft Factory, which is under the direction of the Blackburn Aeroplane Co. Ltd. These machines were fitted with 5.8 to 1 ratio "Lions," and apparently only straight-run spirit of an H.U.C. value considerably below this was available. No benzol was forthcoming, though ultimately the entire supplies

in the country, twenty gallons, were secured from a dye factory and proved sufficient for the first machine. The difficulties with regard to the second machine were overcome by obtaining xylidine from the same source; a six per cent. concentration gave excellent results. As the machine was carrying a torpedo and an overload of 600 lbs. it was most essential that the engine should give maximum power for long periods.

### *Aniline Group*

A wide range of aniline compounds have been tested and mono/methyl aniline is slightly superior to aniline. The further advantage lies in that this former product is soluble in petrols in all proportions, whereas the latter is not. The following table summarises the results obtained with these nitrogen compounds to which have been added other comparative results obtained from certain hydrocarbons and other compounds:—

*Percentage increase of H.U.C.R. obtained with petrol to which has been added 5 per cent. by volume of the following organic substances:*

| Substances. | Chemical Formula. | Boiling Point. | Effect on H.U.C.R. |
|---|---|---|---|
| Benzene ... ... ... | $C_6H_6$ | 80° | 1.0 |
| Toluene ... ... ... | $C_7H_8$ | 111° | 2.0 |
| Xylene (o) ... ... ... | $C_8H_{10}$ | 143° | 0.6 |
| Aniline ... ... ... | $C_6H_7N$ | 184° | + 21.7 |
| Methyl-Aniline ... ... | $C_7H_9N$ | 194° | + 22.2 |
| Ethyl-Aniline ... ... | $C_8H_{11}N$ | 204° | + 10.4 |
| Toluidine ... ... ... | $C_7H_9N$ | 200° | + 18.3 |
| Xylidine (*m*) ... ... | $C_8H_{11}N$ | 215° | + 22.3 |
| Cresol ... ... ... | $C_7H_8O$ | 190° | + 5.8 |
| Phenol ... ... ... | $C_6H_6O$ | 181° | + 4.4 |

### *Detonation*

So far an endeavour has been made to outline the source of supply of light fuels either fully available, being developed or worth developing. The general characteristics of these where employed singly or as mixtures have been dealt with by no means fully, but in a general way.

Not much has been said directly of that serious phenomenon detonation, of which no adequate explanation yet exists. This problem has been the subject of most exhaustive researches led originally by Ricardo and pursued by others who at intervals have added to the available knowledge. It would be impossible to mention all who have attacked this problem from different angles or to discuss in detail the numerous theories that have been advanced. The early works of Tizard in collaboration with Marshall and Pye are of the utmost importance in that they have been responsible for laying in a large measure the basis for an examination of the physical and chemical actions that take place. The recent work of Callendar, King, Sims and Mardles should be carefully studied by all who are interested in this problem, as also should that of Fenning at the N.P.L. Further contributions may also be expected from the technical staffs of the great Oil Companies.

The liability of fuels to detonate as expressed by their H.U.C.R. determine the efficiency with which they can be employed and therefore a complete understanding of this phenomenon is necessary before such a desirable end can be achieved. Much of the work that has been done has served to show that apart from the character of the fuels themselves, there are various features in engine design which must be the subject of special consideration if high thermal efficiencies are to be obtained. The importance of the shape of the combustion

chambers, the type of valve mechanism employed, or the position of valves if of the poppet variety, or of that of the sparking plugs is now fairly well understood. That this is only of comparatively recent origin may be gained from the fact that Mr. Ricardo tells us not long ago that a very prominent firm of motor vehicle manufacturers submitted an engine for test, the detonating qualities of which could hardly have been better even had the engine been specially designed to show to the full this undesirable trait. Although the important features of engine design may be fairly well understood, the behaviour of the fuel-air mixture has been a matter of considerable speculation and has given rise to controversy and the advancing of a multitude of explanations. Not long ago in America an interesting treatise on this subject by Messrs. Clark and Thee gives as a reason why no clear fundamental explanation has been offered the fact that there are at least sixteen variables which must be borne in mind. Their investigations led them to discuss some eight possible theories for the cause of detonation, but in the main they reach the idea propounded by Ricardo and held by many others of the spontaneous ignition of a portion of the unburnt charge. Their visual examinations showed that the detonating portion of the charge is of an intense luminosity, being white and not blue, as is the case with the main portion of the charge that behaves normally.

Sims visualises under the above circumstances the occurrence of very high local pressures possibly reaching a figure of 3,000 lbs. per sq. inch, which would be sufficient to create the phenomenon known generally as "pinking." He further argues that any method of increasing the rate of flame propagation would be beneficial in decreasing the volume of the charge that becomes spontaneously ignited, his estimate of the maximum pressures that might be obtained before this happened being something over 400 lbs. per sq. inch.

The idea of increasing the speed of flame propagation needs some qualification, as this can only cause the amelioration of the conditions partially or otherwise if it is not obtained by an increase of the rate of chemical reaction. Such a condition can be brought about by the employment of substances such as ethyl ether.

A great deal of discussion has taken place as to the relative importance of pressure or temperature, and the most generally accepted theory to-day is that the latter plays by far the most important part. A study of some of the results obtained by Mr. Fenning at the N.P.L. will serve to emphasise this point. The accompanying illustrations of pressure time records of explosions with various fuels show that if detonation is due to spontaneous ignition of the unburned residue, temperature is a controlling factor.

Amongst other interesting points that have been shown is the effect of rich mixtures in intensifying detonation. In the tests referred to the highest pressures were registered with a petrol/air mixture poorer than that theoretically calculated for the complete combustion.

Another line of thought has been very extensively dealt with by Professor Callendar, namely, the "nuclear" theory. It is known that the heavier paraffins are particular offenders in their liability to detonate. It is also said that these bodies when compressed are liable to persist in the form of nuclear drops, and it is argued that in this state they act as a foci of self-ignition under compression, their ignition temperature being low. This led to the examination of various bodies, and it is evident that those of low ignition temperature are the worst offenders. Ricardo, by adiabatic compression, obtained the following figures:—

| | Temperatures. |
|---|---|
| Heptane ... ... ... ... | 330°C. |
| Cyclo-hexane ... ... ... | 387°C. |
| Benzene ... ... ... ... | 419°C. |
| Toluene ... ... ... ... | 422°C. |
| Ethyl alcohol ... ... ... | 514°C. |

These results were obtained with mixtures containing one part by weight of fuel to fifteen parts by weight of air.

Callendar in support of his nuclear theory argues that the beneficial action of metallic substances such as tetra ethyl had is due to the fact that they infect the nuclear drops and delay detonation by keeping down their temperature due to the effects of radiation.

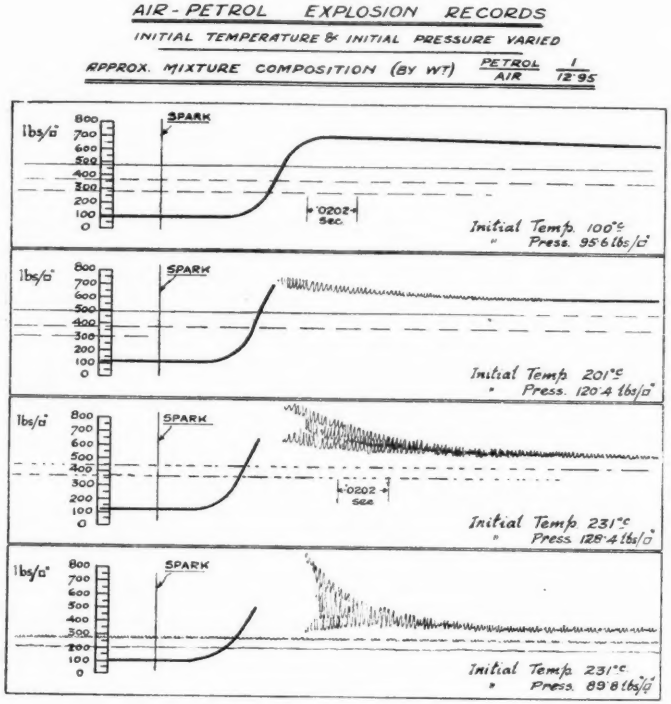



FIG. 16.

The whole subject is so complex that even were the paper to be on detonation alone, a lot would remain unsaid. It is therefore impossible to deal in detail with other important considerations that come in as factors affecting this phenomenon. Questions such as dissociation at high temperatures, rate and range of burning, change of specific heat and such like, have been quite recently dealt with in a highly detailed manner by those whose names have been mentioned before. It is therefore quite unnecessary to emphasise here that the complete understanding and curing of this problem is the most important that concerns the internal combustion engine to-day.

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It is obvious that the most important source of supply of light fuel is at the moment petroleum. There are, as has been mentioned, other sources the further exploitation of which is not only necessary in order to add to the greatly dwindling supplies of petroleum, but also to make these supplies available for use to a greater extent and in a more economic manner.

No startling or sudden changes in the basic fuels used or fairly carefully investigated to-day can be visualised in the immediate years to follow. That there will be some time very great changes no one can doubt, but the forecasting of their arrival is somewhat outside the sphere of a paper of this kind, that aims at being practical. Such speculations, too, would almost certainly be misleading.

Although in this paper an endeavour has been made to set before you some of the many questions affecting the supply and use of fuels to-day, petrol and similar substitutes have been mostly in mind. In endeavouring to set before you for further thought and discussion some remarks on the fuels of to-morrow it must not be thought that the use of distillates such as kerosene has been forgotten. The recent researches at the R.A.E. and Messrs. Beardmore's and Ricardo's, although unfortunately not completed, or in any case not available for publication, are meeting with a substantial measure of success, which is rapidly being translated into practical form by the production of new types of aero engines. Not only has consideration been given to the burning of kerosene, gas oil and such like distillates, but thought has also been given to the employment of residual products such as fuel oil and the like. The employment of hydrogen with kerosene is an extension of those early tests carried out successfully with hydrogen and petrol by the old Airship Section of the Royal Naval Air Service, and the fact that we are fortunate enough to see an early revival of these craft brings the matter once more to the fore. Unquestionably, only extended use of engines consuming this type of fuel for aircraft purposes can give the answer to many of the considerations that arise. This will take some years at least, although it is not improbable that economic changes amongst others may tend to hasten the attainment of results.

The ever-increasing tendency is to find means of obtaining greater thermal efficiencies with all available fuels. The extensive use of benzol for aviation purposes in a mixture with petrol, and the possible use in the near future of alcohol for similar purposes, all lead in the desired direction.

It is considered that the fuels of the immediate future will be the same as those used to-day, but the source of supply will of course be considerably augmented, and alcohol, as yet playing a negligible part, will come into greater use. The principal factors that will enable the attainment of desired results that have been briefly outlined above are the following, and in their fulfilment lies, in the writer's humble opinion, a forecast of the fuel solution of the immediate future:—

(*a*) The extension of research on engine design, not only from the point of view of improvements in design, but from the point of view of the bearing such work will have on the use of fuels other than petrol and the like, and the relation of same to the points below.

(*b*) The discovery of a dope that will suppress detonation when added to fuels in small quantities. Such a substance should be readily available in the quantities required, and at an economic figure. It must be free from all deleterious effects and should for preference be a non-metallic substance.

(*c*) The extension of cracking as a means of yielding more light fuel, particular attention being given to such factors as control the H.U.C. value of the ultimate product.

(*d*) The extension and improvement of existing means of winning the light fuels produced in the various processes to which coal is subjected, and the legitimate encouragement of such systems as will enable coal now consumed in the raw state to be treated and utilised more economically.

(*e*) The creation, where economically possible, of methods for the supply of alcohol by means of fermentation, or synthetically.

## Discussion

The Chairman, after commenting upon the value of the address, joined with the Master of Sempill in expressing satisfaction that the restrictions had been removed from German aviation, because he considered air transport was an international concern. So long as there were international restrictions and obstructions, this new industry would never flourish; co-operation was necessary. Under these conditions of freedom, the nation which could produce the best aircraft and the best personnel would reap the greatest benefit, and he personally believed that that nation would be the British nation.

Mr. H. E. Wimperis considered the Society was fortunate in having added to its Proceedings an account of aero engine fuels which was so lucid, so carefully thought out and so erudite as that prepared by its new Chairman. The Air Ministry had been very glad to give him such official help as was possible, particularly—there was always a reason for these things—because he not infrequently brought to them new and mysterious substances with alleged new and mysterious properties, which they were naturally interested to explore. In fact, one could picture him bringing to the Ministry large quantities of these substances, wondering perhaps whether he was producing something of tremendous importance, or one of those other substances which, according to his lecture, were useful for treating camels which had the mange. Towards the latter part of the lecture the Master of Sempill had dealt with the important questions of compression ratio and detonation. It seemed to him that what one desired in the aero engine was freedom from restrictions due to the fuel. We wanted, on the one hand, to increase the compression ratio for the sake of increased efficiency, and on the other to restrict the compression ratio, because a high maximum pressure meant greater thickness, and therefore greater weight, in the cylinder walls, and greater weight in the engine parts altogether. We naturally wished to aim at the point at which we obtained the maximum of the advantages with the minimum of the disadvantages. The moment, however, we tried to operate the engine at a compression ratio of, say, 7 to 1—which is probably not far from the optimum—we found we were hindered by the fact that the average fuel would not stand that high compression ratio without detonation. The average fuel detonates at a compression ratio more like 5 to 1, so that the ratio of 7 to 1 was quite out of the picture. We wanted freedom to work the engine at the point which seemed best from the efficiency point of view, and benzol was so useful as a fuel constituent because it gave a certain amount of that freedom. It would be exceedingly useful, however, to be able to find a really effective "dope," and he assured the Master of Sempill that research would be pursued steadily in that direction. It was unfortunate that the substances which had to be dealt with were so unpleasant. They were poisonous, or they caught fire, or they had such an evil smell that the investigators could not go home afterwards, but in spite of those disadvantages the research was proceeding and already an amount of information had been obtained which, at any rate, indicated alternatives to the tetra ethyl lead, which was the first in the field. Tetra ethyl lead had been tried on an air-cooled engine and a one hundred hours' run showed no ill effects on the engine.

Wing Commander T. R. Cave-Browne-Cave said they were all indebted to the Master of Sempill for his lecture. Had the title, "Aero Engine Fuels of To-day and To-morrow," been "Aero Engine Fuels of Yesterday and To-day," or "Fuels for Petrol Engines of To-day and To-morrow, with Particular Reference to Motor Car Engines," he would have entirely agreed, but he considered that the aero engine fuel of the future—and the by no means distant future—would be heavy oil, as distinct from the petrols and similar fuels referred to in the paper. Of all the aircraft materials used at the present time the worst was the petrol, and if members considered how comparatively near we were to

being able to use the far safer heavy oil, he believed they would agree with his submission. The importance of making the step from the use of petrol to the use of heavy oil was enormous, and the more one thought about it the more one was impressed with it. In order to fix ideas, he suggested a Diesel oil with a flashpoint of, say, 200 or 210°F., which could be obtained all over the world. There was no restriction of sources, and instead of its price being reckoned in shillings per gallon, it cost £5 per ton.

Examining the advantages of using such a fuel, he referred first to the military aspect. He imagined, for instance, the position of a pilot in what might fitly be described as a "petrol" machine, confronted with the task of shooting down an enemy who had no petrol, but whose aeroplane was fitted with a heavy oil engine. The only way to destroy the enemy was to shoot the pilot in a vital spot. If, however, the enemy fired through any of the petrol tanks of the attacking machine with an incendiary bullet, he destroyed the attacker.

With regard to the commercial advantages of heavy oil, he considered that by far the best summary of the requirements of the commercial aeroplane was that set out by Sir Sefton Brancker in his Inaugural Address to the Society in 1925, and it was well worth while re-reading that address and noticing exactly how far the requirements in it were met by the substitution of heavy oil for petrol. Heavy oil immensely reduced the fuel cost and the insurance risks, the chief items of operating cost. Perhaps more important still, the confidence of the public would be greatly increased.

The next point, obviously, was to consider the possibilities of getting such an engine. The first thing to do was to disregard entirely the marine Diesel engine weighing 400 lbs. per h.p., and the electric generating Diesel engine weighing 40 lbs. per h.p., and to tackle the aviation engine as such. If one wished to develop a small steam-driven motor car it would be unwise to start from a railway locomotive merely because it used steam. Start rather from a satisfactory small car and modify only those parts necessary to allow a steam engine to be used. One must start from the suitable point nearest to the objective and modify as little as possible. The thing nearest to the aircraft C.I. engine was the aircraft petrol engine, and that should be taken as the starting point. In the first place we could dispense with the carburettor, induction pipe, magneto and armoured ignition leads. Then we should find that the cooling of the Diesel engine was considerably easier than the cooling of the petrol engine, because the cycle was more economical. Then we should necessarily have a considerably higher maximum pressure in the compression ignition engine than in the petrol engine—say double the maximum pressure. Therefore, it was necessary to increase the weight of certain comparatively few parts of the engine to take that bigger load. The majority of the engine, however, did not require any increase of weight. The cooling fins of an air-cooled engine or the radiator of a water-cooled engine, for instance, required no increase at all. The piston and the connecting rod had to be heavier, but then one was pleased to find that the increase of those weights increased inertia forces which, as they were opposed to the explosion force, decreased the load on the big end bearing. But then in burning the fuel the trouble began, and it was at that point that really careful and extensive research was required. The whole difficulty centred about getting satisfactory burning at very high speed in comparatively small cylinders.

He assumed that that had been done, and that as a result there was an aero engine which weighed 3 lbs. per h.p. instead of the petrol engine of 2 lbs. per h.p.—he made that prophecy with perfect confidence. That engine would burn 0.4 lbs. per b.h.p. hour, instead of 0.5 lbs. per b.h.p. hour as the petrol engine did, and in ten hours would have made up the 1 lb. h.p. difference in engine weight.

René Fonck, in his Atlantic aeroplane, had a 36 hours' supply of petrol. It would have paid him to use compression ignition engines weighing, instead of 2 lbs. per h.p., 5.6 lbs. per h.p. With engines weighing 3 lbs. per h.p., his engine and fuel weight would have been decreased by 13 per cent., his fuel weight by 20 per cent., fuel volume by 24 per cent. and the cost of fuel by a small fortune. If there were devoted to the development of this high speed compression ignition aero engine anything like the amount of energy, talent and money that was devoted to the development of very special petrol fuels and their dopes, we should get that compression ignition engine comparatively quickly. That engine would probably be no good for motor cars. The power of motor cars was not sufficient to justify the change. That was perhaps fortunate, because a compression ignition engine likely to upset the present motor car makers might meet with considerable difficulty. At the same time, the light, high speed compression ignition engine would introduce an enormous new field; locomotives, marine craft and high speed Diesel generators. Anything within reason was justifiable in order to get rid of these comparatively dangerous and complex fuels of the present day, with their restricted sources of supply, and the dopes with their complex names—of even greater complexity than his own (laughter). "Dope" was a good enough name. Like other dopes it was only justified as a temporary palliative for trouble for which there was a far better and a permanent cure.

Commenting on a sentence in the lecture that in the event of war the bulk of the supplies of benzol would be required for making explosives, he said it was to be hoped that when the next war came the importance of aircraft would be sufficient, and sufficiently widely recognised, to ensure that if they still required benzol, which he hoped they would not, it would be the makers of the then obsolescent high explosive shell who would be informed that they must find a substitute.

Mr. Alan E. L. Chorlton suggested that the aero engine hardly received sufficient attention at the hands of the Society, and that if during the present session a summary of all that had been done in the engine world were given, it would be equally as interesting as that given by the Master of Sempill in relation to fuels. Wing Commander Cave-Browne-Cave, though he had dealt very forcibly and very properly with the question of applying the compression ignition engine to aircraft, had not said as much as he might have done. In the general aeronautical world he thought there was too much talk about adding these wonderful substances to petrol and the great gains resulting. He could understand this as interested parties were doing their best to retain and maintain the present engine. Fundamentally, however, the present engine could not continue. Greater economies were essential, and in order to obtain the greatest economy it is necessary to go to the higher compression ratios. The highest compression ratio was to be found in the injection engine, and as that engine used fuel injected direct into the cylinder about the end of compression, it required no dope. Any fuel that would burn could be used. This need for economy, coupled with the reduced quantity of fuel carried, would lead to the high compression ratio, the crude oil engine being used and, hence, any need in aero practice for these dopes would be "washed out," he believed, in about a couple of years, that is, so far as aero engines were concerned. It was unnecessary to stress the question of safety; whereas in a petrol engine the fuel in vapourising was exposed in a more or less open carburettor, with an injection engine the fuel was injected straight into the cylinder, when all valves were closed; thus, the whole system constituted a closed circuit with its intrinsic safety, apart from the fuel used. Discussing the progress made in the production of such an engine, he said that the injection and combustion parts of it had been in a tried out state for nearly three years. The main difficulties had been concerned with the mechanical parts of the engine, notably in the crankcase and in the crankshaft, and therein lay

the main reason for the delay. The engine should have been in use three years ago. The hypersensitiveness of the officials of the Air Ministry was too intense for evolutionary work.

The requirements on the mechanical side, he considered, had really been over-stressed, and the Ministry should have been more courageous and should have gone ahead, instead of exhibiting such fear about vibrations in the shaft. In regard to weight, probably in a long crankshaft engine the torsional vibrations were of greater amplitude with the maximum pressures, and as there was no compensation from other forces, the weight tended to be high. With a radial engine, however, any extra weight might be provided by reducing the fins area; further, there was not the risk of trouble being experienced with a long crankshaft, and he personally saw no reason why, as the result of the research that Wing Commander Cave-Browne-Cave had asked for, we should not have a radial air-cooled engine as light as the ordinary engine. Wing Commander Cave-Browne-Cave was not ambitious enough with regard to economy. A consumption as low as 0.35 lbs. of fuel per b.h.p. hour had been attained, and with extended research on, say, a 16 to 1 ratio, he was hopeful that within two years that figure could be reduced to nearly 0.3 lbs. per b.h.p. hour. If that could be done, how was it possible to continue working with the present engine, which, by means of these wonderful dopes. could only reach a compression ratio of 7 to 1?

Dr. THOLE (Chief Research Chemist, Anglo-Persian Oil Company) said that during recent years compression ratios had been increased so drastically that, speaking generally, the improvement in anti-detonating qualities of motor spirit had not kept pace with the demands made upon them. Addition of benzole, the palliative at present employed for aviation spirit, was open to the grave disadvantages that the supply was limited, and in the event of war a large proportion must be diverted to the manufacture of explosives. The centres of production would also be exposed to the risk of destruction by hostile aircraft.

The production of cracked spirit would ease the situation to a certain extent, though not to a large degree, for cracked spirit, though less prone to detonation than straight spirit from the same parent petroleum, was not markedly superior. The "power spirit" described by the lecturer was, of course, quite exceptional in anti-detonating qualities, because it was made from a chemically ideal cracking stock, a Russian kerosene so highly naphthenic that it would probably drive an ordinary motor car engine with less detonation than the average petrol. The exclusion of cracked spirit from the Air Ministry Specifications for Aviation Spirit was no doubt justifiable in former days, when cracked spirit was poorly refined and apt to give gummy deposits; such improvements had been made in the technique of refining that it may be anticipated that this restrictive clause will vanish in due course.

The metallic dopes had received a good deal of praise and a good deal of criticism—both thoroughly deserved. The criticisms are so definite and so serious that it seems doubtful if these substances will offer any solution of the problem.

The aromatic amines offer much more promise. They are about ten times as effective as benzole, so that the amount of aromatic hydrocarbons necessary for their manufacture is not a serious proportion of the available supply. In fact many petrols contain sufficient aromatic hydrocarbons to supply all the raw material for this purpose.

A general view of the situation seems to indicate that no one method of improving the petrol will solve the present difficulty, but that different methods or combinations of methods depending on the spirit available and the grade of spirit required will have to be used.

During the next year or two it is probable that we shall see much more improvement in engine design than in the nature of the spirit. Until very recently practically nothing has been known regarding the details of engine design which

promote or inhibit detonation. The position of valves and sparking plugs, the shape of the cylinder head and of the piston, the effect of the degrees of turbulence which these factors induce have not received a fraction of the research which had been devoted to fuels, and the striking results claimed (and in the first case well substantiated by experience) for the Ricardo turbulent head and the Dumanois stepped piston indicate the great scope for improvement in engine design.

The foregoing comments are applied essentially to the aero engine fuels of to-day and to-morrow. It seems beyond doubt, however, that the future will be with the internal combustion engine (the Diesel) rather than with the internal explosion engine which requires a specialised fuel of comparatively limited supply and high fire risk. There will always be need for the explosion motor and petrol, but there are strong indications that the heavy oil engine will largely replace it for aircraft use.

Sir FREDERIC NATHAN (President of the Institution of Chemical Engineers) said that as the result of his study of the possibilities of the Empire production of alcohol for use in internal combustion engines, he had come to the conclusion that it would be impossible to produce it in this country in quantities sufficient to be of any material use as a substitute for petrol. The same position did not quite obtain in the Empire overseas, however. In most cases the requirements were comparatively small, the price of petrol was higher than in this country, and there were possibilities of producing suitable raw materials. The first of those raw materials was molasses, which, in the sugar producing countries, was very often wasted. Also, owing to climate and soil, tropical and sub-tropical countries were capable of producing materials such, for example, as cassara and sweet potatoes, which, although they were foodstuffs, could still be grown in sufficient quantities. The production of alcohol for power purposes on these lines is already an established fact in Queensland, where one big distillery had been erected and two more would be commenced early next year. Another source of material for producing alcohol was the so-called inexhaustible supply of vegetation resulting from the new energy, and also waste vegetable materials, such as straws, mealie cobs, etc. It was true that there were very large quantities of these materials available, but as the result of inquiries he had made, he was advised that although these materials existed in most of the Dominions, Colonies and Protectorates, the cost of their collection and transport to any place at which they could be dealt with on a sufficiently large scale would make the production of alcohol from them an uneconomic proposition. On the whole, therefore, alcohol should not be regarded as a possible substitute for petrol to any material extent. Personally he was inclined to think there was more promise in other liquids, such as the light oil obtained from coal by hydrogenation, although, so far as could be seen, that would not be available in the very near future, and synthetic liquids obtained from hydrogen and carbon monoxide, a more probable source. The latter process had already resulted in Germany in the production of methyl alcohol on commercial lines and in very large quantities. The same process, or modifications of it, had been worked in France by Patart and Audibert with equal success. In this country methyl alcohol had also been produced experimentally. Although he did not know much about utilisation, he fancied that methyl alcohol by itself would not be an ideal fuel, but a process which would produce methyl alcohol had every chance—as experimental results had shown—of producing the higher alcohols, which would be suitable. Strange to say, experiments conducted by Patart had shown the feasibility of the production of the higher alcohols, but for some reason he had been unable to explain methyl alcohol was not produced. The "Synthol" process of Fischer and Tropoch, which was on the same lines, was also making considerable progress in Germany, and it had the additional advantage that it did not require very high pressures and temperatures. Therefore the production of internal combustion

engine fuels by synthetic processes could be looked for with more confidence than the production of alcohol either by the fermentation of materials containing sugar and starch—which were usually foodstuffs—or from materials of a cellulosic nature, such as grasses and waste vegetable materials.

Wing Commander HYNES referred to the valuable service performed by the lecturer in collecting together, in a convenient form for reference, a very large amount of information relating to fuels, which would otherwise be scattered and more or less inaccessible. A review of a subject, such as the one dealt with in the lecture, was of the greatest assistance to those interested in a more general rather than specialist way, in such a complicated question. He considered that the battle between the heavy oil engine and the petrol engine was bound to become more intense, because it was fairly certain that before very long we should be in serious difficulties with regard to supplies of light fuels if the rate of consumption continued to increase as at present. If the big users of light fuels could use heavy oils, a very great saving of the former would be effected. It was worth while remembering the fundamental difference between the petrol engine and the heavy oil engine when running at a reduced output, from the point of view of economy. In the ordinary explosion or petrol engine the reduction of power was obtained by throttling and reducing the charge and, in effect, reducing the effective compression ratio. In the case of the heavy oil engine, however, it took in a full charge of air at every stroke, and the power control could be arranged purely on the amount of fuel injected per stroke. It had been shown very clearly by experiment that in the heavy oil engine (within certain limits) as the power output diminished the economy could be increased in a very marked degree. That was rather important from the point of view of aircraft, particularly civil aircraft, which required maximum power for getting off, so much so, that the aircraft companies might be prepared to put up with fairly serious consumptions or even waste of fuel for the relatively short period of "taking off." The question of using alcohol, etc., for a short time, in getting off, had been seriously discussed in spite of the extra complications and high rate of consumption by weight. The compression ignition engine would enable them to use high maximum power at a rather excessive consumption for a short period, and then to attain maximum economy when the engine was throttled down. It was very difficult to get a petrol engine with a carburettor having those characteristics. There was no doubt that the compression ratios in petrol engines were increasing, and we should get greater economy than we were accustomed to at present. The problem of producing suitable dopes appeared to be extraordinarily complex, but even for small car engines such dopes would be of great value. There was an enormous difference in petrols from the point of view of detonation, and if we could make sure of supplies of fuels which would enable higher compression ratios to be used, the 12 h.p. class of engine would be more efficient than it is to-day. For big engines, however, of 100 or 200 h.p. and above, or even engines of the motor 'bus sizes—which now used colossal quantities of petrol—the future would probably lie with the heavy oil type.

Mr. M. L. BRAMSON referred to his experiences in connection with the production of alcohol from sawdust, in the South of France, some years ago, when he was given a formula, which was German, and was supposed to be perfect, but which did not turn out to be so. The process consisted in converting the cellulose of the sawdust—of which there was a percentage of 60 or 70 per cent.—into glucose; when a good solution of glucose was obtained it was allowed to ferment and alcohol was obtained. In the first place, the percentages of glucose which could be obtained in practice were very different from those obtained in the laboratory, for the reason that the treatment which was necessary on the big scale destroyed the glucose which had been formed. In addition, the organisms which produced the alcohol by fermentation did not like alcohol when there was

too much of it, and when the strength of the solution was round about 12, 14 or 15 per cent., fermentation practically ceased. As a result, there was always a large quantity of water to be got rid of, which cost money and coal. Therefore, he agreed that alcohol as a fuel was more likely to be obtained in the future by the synthetic rather than the fermentation processes. Finally, he urged that there should be a means of utilising fuels in such a manner that in their selection all qualities other than their calorific value could be ignored.

Mr. W. H. SAYERS (*communicated*): The recent paper on fuels raises a number of very interesting points. One of them—that of the future sources of fuel supply in this country—is, I think, of much wider importance than seems to be generally recognised.

Britain is essentially an industrial nation. Originally it acquired an industrial supremacy almost entirely because both coal and iron ore in large quantities were available in close juxtapositions. The combination of the two was important because transport facilities were poor. To-day conditions have changed very considerably, and I think it may be said that industrial prosperity now depends mainly upon an abundance of cheap power, for transport facilities permit of moving raw materials to places where the necessary power is available to fashion them into merchantable commodities. Power for industrial purposes is required in a multitude of forms, but apart from water power, it is eventually all derived from fuel and the community with the best fuel supplies is likely to become increasingly at an advantage in industrial prosperity.

In this country we have coal, and from coal power in all the forms necessary for industrial success can be obtained. There is very little room for doubt that given reasonably economical and intelligent use of our coal resources this country could become very much more nearly independent of foreign supplies—even for liquid fuels—than it is.

The idea that such independence of foreign supplies would be beneficial is not based upon any theory as to the advantage of replacing imports from abroad by the products of British labour, the advantage is essentially that by treating our coal properly we should get better value from it, make it really more useful. Obviously, in time of war there is another and more direct advantage in having fuel supplies independent of external transport services.

Experience of recent years has however shown that there is a very serious weakness in our dependence upon coal as practically our sole source of power. The effect of a coal strike would become very much more serious if it were to cut off supplies of fuel for road transport, as it would do if we drew liquid fuels from the distillation of coal.

It is therefore desirable that if possible some alternative to coal as a source of supply for fuels should be available. If such an alternative can be developed it would at the least have a stimulating effect on the coal industry and tend to accelerate progress in the economical gaining and utilisation of that material. Alcohol derived from vegetation has been suggested as a possible alternative source, but as is stated in your paper, it is not a very hopeful alternative except under very special conditions. It is, I think, hopeless in Britain even for the limited purpose of running the lighter types of I.C. engine.

I find it difficult to believe that alcohol production can be really worth the candle. Coal is only vegetable refuse, probably partly decomposed by some form of fermentation and thereafter subjected to high temperatures and pressures. In the process of decomposition and carbonisation all the more complex and unstable compounds of living vegetable matter have broken down, and it is pretty certain that some highly useful but volatile products of the process have disappeared.

The inference is that everything that can be produced from coal can also be obtained from fresh vegetable matters, and there is very little room for doubt

that hydrocarbons of practically any desirable type, plus solid fuel and a number of useful by-products, can be obtained from vegetable matter by distillation processes. That there are serious difficulties to be overcome is obvious. I believe, however, that it would be found that a much wider range of vegetable substances could be used as a source of fuel by distillation than can be used for the production of alcohol by fermentation, and that much larger yields of useful products might be expected.

Wood, of course, is regularly treated by distillation processes and yields of up to 150 gallons of liquid fuel per ton can be obtained. A good deal of wood is reduced to waste in all industrial countries, and chips and sawdust could certainly be more economically used than they generally are to-day. But wood, like coal, takes a long time to produce and available supplies will not go far towards meeting our liquid hydrocarbon needs.

Green vegetation is another matter, and this will pretty certainly prove amenable to carbonisation and distillation. The main difficulty is the high water content and the consequent large volumes and weight of raw material which must be handled. This difficulty is the worst snag in the way of alcohol production, but may be very much less serious in the case of a carbonisation process. Local drying out of the cut vegetation at the place of growth usually leads to decomposition which may have very serious effects on any subsequent fermentation process. And even if drying out can be safely undertaken at the place of origin, the raw material has to be re-wetted for fermentation, and the added water evaporated by a process of distillation afterwards.

Decomposition which might seriously upset fermentation will probably not interfere with a carbonisation process, and in any case it will not be necessary to re-wet the material. Also there ought to be a much larger useful yield from carbonisation than from fermentation.

On these grounds I cannot help feeling that the problem of carbonising recently grown vegetable matter is well worth study and experiment. Has it, so far as you know, received any attention of recent years?

Apart from the suggestion that the possibilities of distillation from vegetable matter are worth considering, the only points I feel worth bringing forward are to agree with Colonel Cave as to the probable future of the compression ignition engine, and on the basis of a little experience of ethyl gas in an engine rather prone to pink, to emphasise the great value of a satisfactory " dope " as a means of bringing any old fuel to a satisfactory state as regards detonation.

Mr. J. KEWLEY (Chief Chemist of the Asiatic Petroleum Co., Ltd.) (*communicated*): The division of crude petroleums into two main classes, paraffin base and asphalt base oils, though in general use, can only be regarded as a very rough classification. Any classification should be based on the characters of the hydrocarbons of which the crude oils are composed. The number of hydrocarbons is legion, and the number of classes of hydrocarbons is sufficiently great to make a sound classification of crude oils a matter of great difficulty. From the motor fuel standpoint, however, the problem is not so difficult as when all the constituents of the crude are to be taken into consideration.

The division of the more volatile hydrocarbons into paraffins, naphthenes and aromatics is general. It must be realised, however, that each of these classes contains members which may differ widely in character, perhaps as widely as do members of the main groups.

When paraffins are spoken of, the normal or so-called straight chain bodies are usually meant. There are, however, series of isomeric or branched chain paraffin hydrocarbons of similar chemical characters, but very different in respect to their detonation effects.

Thus normal heptane and octane are bad detonators. An iso-octane has recently been prepared by Edgar which has a remarkably good H.U.C.R.

There is every reason to believe that many iso-paraffins also behave well in this respect, and there is no doubt that in many petroleums such iso-paraffins are found in large proportions.

The problem of the complete determination of the constituents of a motor spirit is so exceedingly complex and the difficulty of obtaining quantities of the various hydrocarbons sufficient to allow of the examination of their relative H.U.C.R.'s is so great that the idea of evaluating a motor spirit from a laboratory determination of its constituents must for long remain merely a dream. In general, however, the lower members of the aromatic series are the best from the anti-detonation point of view. It is therefore in the direction of the production of these hydrocarbons that improvements in motor spirits may be effected. It is well known that, within limits, the higher the temperature of cracking, the higher the percentage of aromatic hydrocarbons in the product.

Further attention will undoubtedly be given to cracking under such conditions, probably in the vapour phase, and may be confidently expected to yield good results.

In regard to the action of ethyl fluid, my experience has shown that the increase of H.U.C.R. produced by a given proportion of dope does bear a relation to the original H.U.C.R. of the fuel. The lower the H.U.C.R. of the fuel the greater the proportion of ethyl fluid required to bring about a definite increase in H.U.C.R. Thus, in the cases of three fuels of H.U.C.R. 5.09, 5.59 and 5.73, the addition of the same percentage of lead tetraethyl increased the H.U.C.R. by 0.73, 0.85 and 0.91 respectively.

Dr. E. W. J. MARDLES (*communicated*): At the President's intimation that on account of the lateness of the hour the discussion could be continued by written communication, the following might be of interest and is contributed in appreciation of the excellent lecture.

With the present daily consumption of petrol of over 30 million gallons and the prospect of an ever-increasing demand, we must share to a great extent views expressed again and again that we shall have to face sooner or later a world-wide shortage.

However, as Colonel the Master of Sempill has shown, there is no immediate danger of a sudden cessation of supplies, since modern research and discovery clearly indicate that liquid fuel of high quality and in abundance can be obtained from new sources.

Again, the discovery by T. Midgley, the American chemist, that lead tetra ethyl has a very marked action in delaying detonation in the internal combustion engine, has put us in the happy position of being able to use third rate fuel to do the work of a first class fuel or to convert an ordinary petrol into a good aviation spirit.

It has acted as a tonic to research in this direction and sooner or later we shall have the full story of what really happens in the cylinder during combustion instead of vague and hazy ideas. A precise knowledge of the mechanism of combustion of various fuels is lacking and perhaps it is not too much to say that such a knowledge is very necessary to the design of future aero engines.

Enough has been said concerning the limitations of various fuels that it appears certain that the fuel of the future for aircraft will be a highly complex mixture, synthetised in accord with the many special requirements of aviation. Those of us who are working on the problem of detonation are searching for the ideal anti-detonation substance which will raise the H.U.C. ratio without any possibility of fouling the engine with any solid products of combustion from metallic dopes or residual tarry substances from aromatic bases.

Once we had great hopes that colloidal carbon, which is pyrophoric, might be this "anti-knocker," but the results of our experiments at the Air Ministry laboratory showed that our hopes were in vain.

Professor Callendar has conducted his researches from the standpoint of the nuclear drop theory to search for likely anti-detonating substances available in time of emergency and free from the objections raised against the use of metallic dopes. The selection of these substances or substance might be the forerunner of the synthetic fuel of the future. It has been pointed out that the fermentation industry is not likely to help much in supplying the vast quantities of liquid fuel for the immediate future, but there is hope that a substance might be prepared from the alcohols, etc., by catalytic treatment for example, which would possess a high H.U.C. ratio and could be blended with inferior fuels for aircraft work. The alcohols are not suitable for aircraft, as might be judged from the fact that ethyl alcohol contains one third and methyl alcohol one half its weight of already combined oxygen.

In his forecast of the fuel position of the immediate future, Colonel the Master of Sempill has reached the significant conclusion that an important factor in attaining the ideal fuel will be the engineer's efforts in research on engine design to enable fuels other than petrol to be used. It is to be imagined that in the endeavour to reduce the fire hazard of aviation to a negligible quantity these future fuels will certainly be less volatile and possess a much higher flash point than the fuels of the past.

The CHAIRMAN, proposing a vote of thanks to Colonel the Master of Sempill for his address, recalled the interesting theory that world power depended upon fuel power, and that Great Britain's great world power to-day was due to our supplies of steam coal. The position had been changed, however, and there was a race in progress by all the nations for oil. There had been various depressing forecasts made as to the exhaustion of oil supplies, and he supposed that when that time came we should have to harness the sun. At first sight it would appear that the Sahara would become the most important part of the world, but he believed that when it became necessary to harness the sun, the British Empire would still be the greatest empire in the world (applause).

The vote of thanks to Colonel the Master of Sempill was carried with acclamation and the meeting closed.

Colonel the MASTER OF SEMPILL, replying to the discussion, thanked Major Wimperis for the assurance that the Air Ministry were continuing the investigation of various dopes, and added that as these researches would undoubtedly be carried out with the thoroughness that is characteristic of the work of the Air Ministry laboratory, far-reaching results could be expected in the not too distant future. The reference made by the Director of Scientific Research to tests made with lead tetra ethyl doped fuel on an air-cooled engine was extremely interesting. It is a little difficult to determine as to why these results, which presumably are results obtained on the "Jupiter" engine at the R.A.E., should be so much more satisfactory than those recently obtained with a "Lion" engine. Although it is not definitely stated, it is clear that what is known in America as ethyl fluid was used in these tests.

Dealing with the remarks of Wing Commander Cave-Browne-Cave and Mr. Alan Chorlton, the Lecturer said that he thought that these might be treated together, as they both threw light on important developments of the near future. He had refrained from saying very much about the possibilities of the use of the heavy oil aero engine, as to start with there was not a great deal of information on this subject, and furthermore a good proportion of that which does exist is considered as confidential by the Air Ministry, or Messrs. Beardmore, or Ricardo, who have concentrated their attention on this particular problem. For these reasons, therefore, it had seemed better to say little, but to insure the

presence of Wing Commander Cave-Browne-Cave and Mr. Chorlton, who would be in a position to make first hand contributions to the discussion. Everyone will agree that too much attention cannot be focussed on this problem, and it would appear from the remarks made that perhaps more might be done in this connection, as it will only be as a result of the extended full-scale tests that now appear possible that the advent of the Diesel type engine for aircraft purposes will be hastened. The criticism of the title of the paper can be met by turning it into "Aero Engine Fuels of To-day and To-morrow, but *not* the *Day After*." Wing Commander Cave-Browne-Cave's forecast that all the supplies of benzol would in a future conflict be available for aircraft is interesting as being indicative of the importance of that branch of the country's defence services; if, however, we are to look to the possibilities of such an event in the near future we can hardly rely upon the Air Arm being so specially favoured. It is hoped, however, that Wing Commander Cave-Browne-Cave's prophetic utterance will one day prove true.

Mr. Chorlton has certainly put up a very clear and lucid argument in favour of the compression ignition engine, and from statements made it would appear that the natural troubles that are bound to arise in the production of any new engine have not only been in a large measure overcome, but have not proved of so serious a nature. The production of a radial engine of this type certainly has a great deal to recommend it and it is to be hoped that closer investigation may be given to the possibilities of such a design.

Dr. Thole's remarks on the cracking situation are interesting. He is perfectly correct when he says that the "power" spirit referred to in the paper is a product of cracking Russian kerosene. Russian kerosene is well known to be extraordinarily rich in hydrocarbons not prone to detonation, and therefore, as might be expected, the use of such a charging stock produces a spirit of exceptionally high H.U.C.R. Dr. Thole will however admit, it is felt sure, that there is every reason to believe that cracking under certain conditions does produce a petrol of higher H.U.C.R. than would normally be produced from a similar crude oil by the usual process of fractional distillation. The question is what improvement actually may be expected and what are the factors tending to influence this. Only a lengthy series of tests can answer such a question and Dr. Thole will probably agree that tests in order to be really accurate must be carried out on the full scale. One can join with him in hoping that the Air Ministry will seriously reconsider the position of cracked spirit, at the moment barred by them. It is satisfactory to note that he inclines towards the aromatic amines as a possible source for the supply of "dope." The fact that many of the petrols now supplied contained enough of the particular hydrocarbons for the provision of the necessary raw material answers a point that has been often raised. The scope offered to designers for engine improvements has been stressed in the paper, and there is no doubt, as Dr. Thole has pointed out, that improvements are to be obtained by utilising such devices as the Ricardo turbulent head.

Everyone will agree with Sir Frederic Nathan in what he says with regard to the possibilities of the supply of alcohol, as the existing information is in the main directly attributable to his efforts. Sir Frederic stresses the difficulties that are to be met with in attempting to produce large quantities of alcohol on a commercial scale. The uses of alcohol have been discussed in the paper at some length. It is difficult to understand why, in view of the situation as portrayed by Sir Frederic, and also in view of the recommendation of the Aeronautical Research Committee, no really extensive tests have been carried out by the Air Ministry on the "bi-fuel" system. This system appeared to offer very excellent results and also overcame many of the difficulties that are naturally met with in any endeavour to use alcohol in conjunction with petrol or any other hydrocarbon fuel.

The remarks made by Wing Commander Hynes are really an elaboration of the case put up by Wing Commander Cave and Mr. Chorlton, and it is interesting to note that he is of the opinion that although the advent of the heavy oil type of engine is near, the use of dopes with lighter fuels will still be a matter of some considerable importance.

Mr. Bramson's early experiences of the production of alcohol from wood were obviously beset with many difficulties, and it may be suggested that the more modern methods of production such as carried out by the Prodor and Classen processes would be free from many of these difficulties. At the moment we are certainly not in a position to judge fuels solely by their calorific value.

Dr. Mardles stresses the desirability of ascertaining in detail what really happens in the cylinder during the process of combustion. In this country and in America this problem is receiving a great deal of attention, and it is to be hoped that the credit for its solution may be gained by some of those working on this question over here.

Mr. Kewley rightly points out that the division of crude petroleums into the paraffin base and asphalt base oils is only a very rough classification. This is certainly true as there are exceptions; for instance, Mexican and Argentine oils are generally asphaltic, but the petrol is almost entirely paraffinoid; certain Trinidad crudes are highly aromatic and naphthenic, but asphalt free; so in fact is Burma crude, which contains much paraffin wax and produces a petrol with a high H.U.C.R. The enormous difficulties that beset the chemist who endeavours to determine the constituents of any petrol is a matter for reflection, and that these difficulties should be emphasised by a person of the eminence of Mr. Kewley might well be calculated to frighten others from investigations along these lines. The accentuation of these difficulties only goes to point out that the fundamental test of the value of a fuel is the determination of its H.U.C.R. by the methods touched on in the paper. The forecasting of a return to cracking in the "vapour phase" is extremely interesting, but does seem rather in conflict with the policy of those organisations in America who have been the largest users of vapour phase or liquid vapour phase cracking in the past, but are now gradually replacing such plants by those operating in the liquid phase. The action of ethyl fluid, according to Mr. Kewley, does bear a relation to the original H.U.C.R. of the fuel, although the tests carried out at the Air Ministry laboratory are in this respect in conflict with his experience, but the particular reason for this is not yet apparent.

Captain Sayers emphasises, and cannot do so too strongly, the enormous importance of stopping the many wasteful methods of utilising the country's coal supplies. This is realised by many, but the intelligent use of these resources seems even to-day a long way off. The use of wood waste certainly opens up possibilities with the improved processes now available. The great question, however, of the utilisation of green vegetable matter as suggested by Captain Sayers opens a very large subject indeed and one on which, in so far as I know, no really extensive researches have so far been undertaken. Some of the difficulties that are to be met with are similar to those that have caused Sir Frederic Nathan to reach the conclusions he has told us of regarding the production of alcohol by the fermentation of vegetable matter.

# PROCEEDINGS

## SECOND MEETING, FIRST HALF, 62ND SESSION

The Second Meeting of the Sixty-Second Session of the Royal Aeronautical Society was held in the Theatre of the Royal Society of Arts, Adelphi, on Thursday, October 21st, 1920, when a paper on "Magnesium and its Alloys" was read by Mr. W. R. D. Jones, M.Sc.

Colonel the Master of Sempill, Chairman of the Society, presided at the beginning and his place was later taken by Mr. W. O. Manning.

## NOTES ON MAGNESIUM AND ITS ALLOYS

BY W. R. D. JONES.

The introduction of a new material is a very slow process and engineers are extremely critical of the claims put forward in favour of any new materials. The development of aluminium and its alloys has been exceedingly slow and it has needed the extraordinary circumstances of the war and the brilliant work recorded in the eleventh report of the Alloys Research Committee of the Institute of Mechanical Engineers to establish finally the use of aluminium and its alloys. This paper deals with one of the latest metals to be introduced to engineers.

Magnesium and its alloys have been already used to some extent, but the amount of detailed information which has been published on the properties of these alloys is very small and a great deal of work requires to be done before our knowledge of these new materials is equal to that of aluminium and its alloys. I shall consider the object of this paper to have been achieved if it arouses critical interest in the possibilities of these new materials of construction. It is only after long and careful research by the metallurgist or supplier that any new material can be considered satisfactory for passing on to the engineer or user.

The essential characteristics of any material for general engineering work are freedom from inclusions, reliability, strength, ease of working, and especially in the case of aircraft construction the minimum lightness consistent with these essentials. During this century the science and art of metallurgy has developed tremendously and almost every metal can be obtained cheaply on a commercial scale with more than 99.5 per cent. purity.

The great advance in the study of the physical properties of materials due to the combined activity of the engineer as well as the metallurgist has resulted in the production of reliable material and so reduced greatly the "factor of safety." Metals are now being "understood," and the introduction of scientific control into the workshop has resulted in refuting the criticism that what could be done in the laboratory could not be done on a commercial or works scale.

Engineers recognise the great importance of heat-treatment and the necessity for accurate temperature control. Few works nowadays are without some kind of instrument, even if it is only a $CO_2$ recorder outfit in their boiler plant. The heat-treatment of light alloys and the important tempering temperatures of special steels are often lower than the temperature at which the body gives "colour," so that the use of pyrometers in works is absolutely necessary. Craftsmanship is not being replaced by scientific instruments—the human element

must be always paramount. These instruments have been invented to enable the craftsman to do work which was previously impossible.

During the early development of aluminium alloys scientific control was not practised in the works with the result that progress was slow. The urgent necessities of the war stimulated research and the education of the practical men to scientific control in the works. Data obtained in the laboratory can now be interpreted and used on a works scale with the result that much of the scepticism against light alloys has disappeared and aluminium and its alloys are now very ordinary engineering materials.

Attention has been focussed on the ultra-light alloys owing to the successful development of the light alloys of aluminium and to the fact of the lower specific gravity of the former alloys. All the advantages claimed for the use of aluminium alloys will be enhanced by the use of magnesium alloys provided that the necessary strength and other essential characteristics are there. Without wishing to appear unduly enthusiastic the author is convinced that on development the ultra-light alloys will equal and probably surpass aluminium alloys. A well-known American authority on aluminium—R. J. Anderson—states frankly in his recent book, "Metallurgy of Aluminium and Aluminium Alloys," "No actually sound aluminium alloy casting has ever been made!"

The development of magnesium and its alloys will probably prove much more rapid, owing to the more up to date works control now possible, which has resulted from the production of light alloy castings and forgings.

Magnesium is not a new metal. It was first isolated by Davy in 1808, and in 1864 was first produced on a commercial scale. In 1909 the magnesium alloy elektron was exhibited at an aircraft exhibition held at Frankfort-on-the-Main. The Germans used magnesium-rich alloys during the war, and several parts of the Zeppelin L.49, brought down at Bourbourne, were made of this type of alloy. It is a significant fact that since the war ended the production of magnesium in Germany has been greater than during hostilities. Certain magnesium alloys are largely used in this country, but published information on their general properties is very scanty. However, in a commercial sense magnesium is a very new metal for constructural purposes and its present state of development is the same as that of aluminium about 20 or 30 years ago. Its development is rapid and it will soon be a serious rival of aluminium not only in properties but also in price. The present price is high, but as the number of applications of the metal and its alloys will increase, so will the demand increase production and lower the price. The following table is interesting and shows the very rapid decrease in cost of magnesium since the war:—

TABLE I.—SELLING PRICE OF MAGNESIUM PER LB.*

| | | | | |
|---|---|---|---|---|
| 1918 | ... | ... | ... | 22/6 to 25/- |
| 1919 | ... | ... | ... | 17/6 ,, 20/- |
| 1920 | ... | ... | ... | 12/- ,, 14/6 |
| 1921 | ... | ... | ... | 7/- ,, 7/6 |
| 1922 | ... | ... | ... | 6/- ,, 6/6 |
| 1923 | ... | ... | ... | 4/- ,, 4/9 |
| 1924 | ... | ... | ... | 3/9 ,, 4/6 |
| 1925 | ... | ... | ... | 3/7 ,, 4/3 |
| 1926 | ... | ... | ... | 3/5 ,, 4/3 |

* Information given by the Magnesium Co., Ltd., London.

Aeronautical engineers are particularly interested in the comparison of wood and metal for aircraft construction. The subject has recently been admirably dealt with by M. E. De Woitine,[1] who unhesitatingly advocates the all-metal plane. "Whatever solution may prevail after years of necessary study, I have

[1] *Proceedings Inst. of Aeronautical Engineers*, 1926.

faith in all-metal construction at least for aeroplanes of large tonnage, which without a doubt will become the commercial machines of the future in the same way that metal ships to-day completely replace the wooden ships of days gone by." R. J. Anderson[2] states the case very clearly as follows: "The wood construction of aeroplanes will give way to metal construction because of the general superiority of certain alloys, notably steel and duralumin, over wood. Fire hazard is exceptionally dangerous with 'doped' linen.

"From the point of view of engineering design any structure in metal is better than one in wood because more accurate workmanship is possible; from the point of view of quantity production of parts, metal is of course much superior to wood, consequently, both from the point of view of design and production in addition to other advantages the all-metal airplane is a much more desirable craft to build than the ordinary craft which contains wood. An airplane constructed of metal can also be more readily produced in the streamline shapes which are desired for the best aerodynamical efficiency, and if correctly designed the all-metal craft need not be much heavier than one in which wood is largely used. It will be more durable and practically free from fire hazard provided the gasoline tank is sufficiently well protected."

The all-metal aeroplane has already appeared made from duralumin and has passed successfully commercial tests. Magnesium and its alloys show quite as good possibilities as duralumin in replacing wood in aircraft construction. The following table shows the mass-strength or strength/weight ratios of some woods and metals:—

TABLE II.—MASS-STRENGTH.

| | Mass-Strength. |
|---|---|
| Commercially pure aluminium—cast ... ... | 2.0 |
| forged ... ... | 3.7 |
| Commercially pure magnesium—cast ... ... | 4.4 |
| forged ... ... | 8.7 |
| "Y"—Alloy ... ... cast ... ... | 4.8 |
| forged ... ... | 8.2 |
| Elektron ... ... ... cast ... ... | 5.5 |
| forged ... ... | 9.7 |
| Oak—Dry ... ... ... ... ... | 5.6 |
| Pine—Dry ... ... ... ... ... | 6.2 |

The purity of present day commercial magnesium is remarkably high, as shown by the following published analyses:—

| | (i) | (ii) | (iii) | (iv) | (v) |
|---|---|---|---|---|---|
| Copper % ... ... | .048 | .02 | .069 | .05 | .001 |
| Silicon % ... ... | .075 | .01 | .033 | — | .051 |
| Iron % ... ... | .060 | .08 | .100 | .07 | .050 |
| Magnesium % by difference ... | 99.82 | 99.89 | 99.75 | 99.88 | 99.886 |

(i) S. L. Archbutt, *The Metallurgist*, January, 1926.
(ii) S. L. Archbutt, *Journal Institute of Metals*, No. 1, 1925.
(iii) Hanson and Gayler, *Journal Institute of Metals*, No. 2, 1920 (together with .019 per cent. zinc and .029 per cent. manganese).
(iv) Gayler, *Journal Institute of Metals*, No. 1, 1923.
(v) Material used in Author's experiments.

The physical properties of magnesium are given in the following table and can be compared with those of other pure commercial metals:—

[2] *Metallurgy of Aluminium and Aluminium Alloy.*

TABLE III.—PHYSICAL PROPERTIES OF COMMERCIALLY PURE METALS.

| | Magnesium. | Aluminium. | Zinc. | Tin. | Copper. | Nickel. | Iron. |
|---|---|---|---|---|---|---|---|
| Atomic wt. ... | 24.32 | 27.1 | 65.37 | 118.7 | 63.57 | 58.68 | 55.84 |
| Melting point °C. ... | 651 | 658.7 | 419.4 | 231.9 | 1083 | 1452 | 1530 |
| Boiling point °C. ... | 1120 | 1800 | 920 | 2260 | 2350 | 2400 | 2450 |
| Density ... ... | 1.74 | 2.70 | 7.12 | 7.286 | 8.36 | 8.83 | 7.85 |
| Specific heat at o° ... | 0.2456 | 0.2124 | 0.0934 | 0.0559 | 0.0936 | 0.10836 | 0.1130 |
| Linear coefficient of expansion $\times 10^{-6}$ ... | 25.60 | 23.53 | 29.18 | 23.40 | 17.40 | 12.79 | 12.30 |
| Thermal conductivity, c.g.s. units at 18°C. ... ... | 0.376 | 0.504 | 0.255 | 0.155 | 0.918 | 0.142 | 0.161 |
| Thermal conductivity, Silver=100 ... | 34.3 | 35 | 26.53 | 15.2 (abt.) | 92 | 14 | 16 |
| Specific electrical resistance, microhms per cubic cm. ... | 4.36 | 2.82 | 5.75 | 11.5 | 1.69 | 10.04 | 9.065 ± |
| Electrical conductivity, Silver=100 | 34 | 57 | 25.7 | 15.6 | 94 | 12.9 | 17 |
| Purity ... ... | 99.8 | 99.7 | 99.8 | 99.99 | 99.9 | 99.8 | 99.8 |

In this table both magnesium and aluminium are outstanding by reason of their very low density and high specific heat, and with the exception of copper their relatively greater electrical and thermal conductivities.

All these factors are of direct interest to engineers and many possibilities are apparent. Comparing magnesium with aluminium a great similarity is noted. Both metals have almost the same thermal conductivity, but aluminium is a much better electrical conductor. Even when allowance is made for the lower specific gravity of magnesium there has been no advantage in using magnesium in place of aluminium. The weight of equivalent conductors for copper, aluminium and magnesium are respectively 1,000, 506 and 500. The recent introduction of special treatment of magnesium by the Michel patents, as exemplified in this country by Maxium metal, claims to increase very much the thermal and electrical conductivities.

A further interesting comparison is given in the following table of data of the mechanical properties of various pure metals:—

TABLE IV.—MECHANICAL PROPERTIES OF COMMERCIALLY PURE METALS.

| | Magnesium. | | Alum. | Alum. | Copper. | Copper. | Copper | Nickel. | Nickel. | Nickel. | Iron. | Iron. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Purity ... ... | 99.89 | 99.89 | 99.7 | 99.6 | 99.9 | 99.9 | 99.9 | 99.8 | 99.32 | 99.7 | 99.9 | 99.8 |
| Condition | Chill-cast. | Forged to 1in. dia. from 2½ in. dia. | Chill-cast. | Forged. | Chill-cast. | Forged. | Extruded and annealed. | Chill-cast. | Hot forged. | Annealed. | Hot forged. | Annealed at 1050°C. |
| Limit of proportionality (tons per sq. in.) ... | 0.6 | 8.2 | 2.22 | 6.8 | — | — | — | — | — | 8.4 | — | 9.2 |
| Yield Stress per sq. in.... ... | — | — | — | 8.9 | — | — | — | 9.0 | 8.4 | 10.9 | 11.2 | 10.4 |
| Ult. Strength (tons per sq. in.) | 7.4 | 17.8 | 4.5 | 13.7 | 11.0 | 21.30 | 14.5 | 25.0 | 32.4 | 30.8 | 10.8 | 20.0 |
| % Elongation ... | 7.0 | 8 | 7.0 | 6 | 34 | 20.4 | 56 | 25 | 52 | 44.5 | 49 | 35.0 |
| % Reduction of area ... ... | 5.4 | 16 | 12.9 | 12.0 | 74 | 65.9 | 72 | 27 | 57 | 55 | 75 | 70.0 |
| Brinell Hardness No. ... ... | 30 | 38 | 23 | 39 | 28 | 91 | 47 | 74 | 131 | 123 | 87 | 86 |
| Notched bar impact value, ft.-lbs. to fracture | Negligible. | — | 14C. | 30 | 17.5I. 72.3C. | 45.75I. | 30.5C. | — | — | — | 23.9C. | 35C. 53.79I. |

In the cast state magnesium is stronger than aluminium but is weaker than other metals. The properties are, however, greatly improved by forging, becoming very much superior to those of forged aluminium. For engineering purposes a fairer comparison of the properties is obtained if the densities of the various metals are taken into account. This is well shown by either the specific tenacity or by the mass-strength which is the ratio between the mechanical properties and the respective specific gravities. The value "specific tenacity" was introduced by Rosenhain and Archbutt and is obtained by dividing the tensile strength in tons per square inch by the weight in pounds of a cubic inch. These values are shown in Table V. and have been derived from the data given above in Table IV.

TABLE V.—STRENGTH/WEIGHT RATIOS OF COMMERCIALLY PURE METALS.

| Metal. | Condition. | Specific tenacity. | Mass-Strength. |
|---|---|---|---|
| Magnesium ... | cast ... ... ... | 117 | 4·3 |
| Magnesium ... | forged ... ... ... | 247 | 9·0 |
| Aluminium ... | cast ... ... ... | 47 | 1·7 |
| Aluminium ... | forged ... ... ... | 140 | 5·1 |
| Copper ... | cast ... ... ... | 38 | 1·4 |
| Copper ... | forged ... ... ... | 66 | 2·4 |
| Nickel ... | cast ... ... ... | 78 | 2·8 |
| Nickel ... | forged ... ... ... | 101 | 3·7 |
| Iron ... ... | forged ... ... ... | 70 | 2·5 |
| Iron ... ... | forged and annealed ... | 69 | 2·5 |

It is now recognised that it is essential that a designer should know the resistance of his materials to fatigue, *i.e.*, the resistance when subjected to repeated stresses, and it is becoming the practice to include fatigue tests with the more common mechanical properties. This is especially important in the case of the lighter metals in view of the nature of their duties such as their use in aircraft construction and in engine parts.

A comparison of the fatigue resisting properties of the materials quoted above is given together with the endurance/weight ratio in Table VI.

TABLE VI.—FATIGUE RESISTING VALUES OF COMMERCIALLY PURE METALS.

| Metal. | Purity. | Condition. | Endurance limit—ranges of stress, tons per sq. in. | Endurance limit (vi.)/specific gravity. |
|---|---|---|---|---|
| Magnesium (i) ... | 99.9 | forged | ± 3.48 | 2.0 |
| Aluminium (i) ... | 99.24 | forged | ± 4.69 | 1.74 |
| Copper (v) ... | 99.9 | forged | ± 5.6 | 0.67 |
| Nickel (iii) ... | 99.32 | forged | ±13.0 | 1.47 |
| Iron (iv) ... ... | 99.8 | forged | ±12.5 | 1.60 |
| Iron (iii) ... ... | 99.9 | forged | ±10.5 | 1.34 |

(i) H. H. Moore, Research Reports of the Engineering Experimental Station, University of Illinois.
(ii) Hanson, Marryat and Ford, *Journal Institute of Metals*, No. 2, 1923, p. 212.
(iii) H. J. Gough, "The Fatigue of Metals."
(iv) Gough and Hanson, *Proceedings, Royal Society*, 1923, 104, 538.
(v) D. J. McAdam, *Journal American Society for Steel Treating*, 1924.
(vi) The value is taken as half the "range."

An examination of the data shows that magnesium is well entitled to serious consideration as a material of construction, and although its properties when in the "as cast" condition are not striking, its strength is so increased by forging that it will probably find extensive use in the unalloyed condition. Its chief drawback is its low elastic limit, but this is somewhat counterbalanced

by a proof stress of 1.8 tons per square inch. On a weight for weight basis it is superior to every other commercially pure metal used as an engineering material. It is not readily affected by the atmosphere and is slightly more resistant than aluminium. On exposure it becomes covered with a thin adherent bluish-grey film of a mixture of hydroxide and oxide which inhibits further attack. The presence of impurities causes rapid localised corrosion and pitting. Present day magnesium is an exceedingly good product, practically free from inclusions of chloride and slag with the result that the material is not nearly so susceptible to pitting as formerly. It does not appear to scale at temperatures up to 450°C. or up to the ignition temperature. This is an advantage when the material is used for pistons working at high temperatures. It is, however, readily attacked by (weak) acids with the exception of fairly concentrated hydrofluoric acid. It is rapidly acted upon by saline solutions, but is almost unaffected by alkaline solutions.

The burning of magnesium and its use as ribbon or powder for flashlight photography has led to an exaggerated idea of the risk of fire with these alloys. With even moderate care there is no more risk in casting and using these alloys than there is with aluminium. Pure magnesium burns much more readily than any of its alloys. The pure metal will not burn until its temperature is above the melting point and there is excess of air available. When the metal starts to burn it must be dealt with immediately as the heat of formation of the oxide is so high (6,000 cals.) that the burning is propagated. Water should never be used to quench burning magnesium as it will be decomposed with explosive violence.

Should some metal be spilled during casting and burn, it is best quenched by placing a slab of cold iron or steel on it, thereby cutting off the air supply and reducing the temperature below the melting point. The fire is also effectually smothered by dry sand. Some buckets of dry sand should be always in a convenient place in the melting shop whose floors should be kept as dry as possible. Sand should not be used unless absolutely necessary as it reacts with the burning metal, which is lost and cannot be used again.

The risk of burning, however is negligible if care is used. Turnings, when dry, are not liable to spontaneous ignition, but should not be allowed to accumulate owing to the risk of accidental ignition and the possibility of developing heat by contact with moisture. They are best stored in a covered tin box. They can be used as scrap after pressing, briquetting and using about three times the normal amount of flux. Filings and saw cuttings are best collected and burnt in small amounts on a fire, as at present they cannot be profitably used as scrap.

It is quite possible that magnesium will come into greater use as a material of construction than its alloys owing to the fact that its properties are readily improved by correct forging and heat-treatment. In the cast state the metal is coarsely crystalline, and the addition of small amounts (under one per cent.) of an alloying element, such as copper, will refine the grain. This grain refining is also accomplished by forging, with the result that the mechanical properties of the pure metal are improved and are equal to many of its alloys. The chief difficulty has been the production of sound ingots free from gas cavities. The Author and his colleague, Mr. W. T. Cook, B.Sc., have succeeded in casting magnesium with absolute freedom from defects by a method of double melting.[3] Ingots up to four inches diameter have been cast successfully. In preceding tables data are given of the properties of the pure metal in the cast state, 1in. diameter bars and billets of 2½ inches diameter forged down to 1in. diameter bars. It is seen that the forged bars have mechanical properties which place the metal in a very favourable position when compared with other metals and alloys.

[3] *Journal Institute of Metals*, Vol. II., 1926.

In France the addition of small amounts of calcium has been successfully exploited to produce sound castings by M. G. Michel, of Bagneux. British patents No. 247,149 state that calcium, preferably 0.05—0.3 per cent. is added to magnesium or its alloys, and impurities such as chlorides or oxychlorides are eliminated by treating the molten metal with magnesium fluoride. The calcium is preferably added in the form of small particles which may be placed in a thin magnesium tube. The surface of the bath may be covered with a protective material such as ammonium chloride. By the Michel treatment it is claimed that quite apart from the effects of forging, the metal has lost its coarse grain and become fibrous, resulting in a general improvement of mechanical and physical properties. Reference is made to the Michel patents and processes by L. P. Sidney,[4] who states that the metal in the fibrous condition has its heat conductivity increased threefold so that the metal is eminently suitable as a piston material. Its electrical conductivity is far greater in the fibrous condition than in the coarsely crystalline state. This fact will enhance the value of magnesium when compared with aluminium. The sole British licensees of the Michel patents and processes are British Maxium, Ltd., Patricroft, Manchester. The results of tests on a sample of maxium metal kindly given to the Author by the Company are as follows:—

MAXIUM METAL.

| | |
|---|---|
| Limit of proportionality, tons per sq. inch ... ... | 5.0 |
| Proof stress, tons per square inch ... ... ... | 9.1 |
| Ultimate strength, tons per square inch ... ... ... | 14.2 |
| Elongation per cent. on 2 inches ... ... ... ... | 2.7 |
| Reduction of area per cent. ... ... ... ... | 2.8 |
| Brinell hardness number (500 kilogr. load, 10 mm. ball) | 43 |
| Specific gravity at 18°C. ... ... ... ... ... | 1.742 |

The analysis given by British Maxium, Ltd., which is typical of their maxium metal, is as follows:—

| | |
|---|---|
| Magnesium ... ... ... ... ... | 99.668 |
| Iron ... ... ... ... ... ... | 0.025 |
| Aluminium ... ... ... ... ... | 0.200 |
| Manganese and zinc ... ... ... ... | 0.090 |
| Lead ... ... ... ... ... ... | 0.010 |
| Traces of other metals ... ... ... ... | 0.077 |

This material is stated to give average tensile results of 15-17 tons per square inch after being forged.

### *Alloys of Magnesium*

The object of adding small proportions of other metals to magnesium is to increase its strength and to improve its elastic limit. The specific gravity is generally increased so that the addition of the added alloying elements has to be such that the increase in strength is not counteracted by an undue increase in specific gravity, thus reducing the mass-strength ratios. Further, the exploiting of aluminium silicon alloys with a specific gravity less than that of pure aluminium limits the necessity for some at least of the heavier magnesium alloys. The effect of an alloying element on a metal is generally (1) to form solid solutions with the metal resulting in an all round improvement of mechanical properties, or (2) to form intermetallic compounds which are usually insoluble in the metal. These compounds are generally hard and cause an increase of tenacity at the expense of ductility up to a certain amount. Beyond this there is an embrittling effect and a general decrease in mechanical properties, and the alloys lose their toughness and are difficult to work.

[4] *The Chemical Age*, November 7, 1925.

Of the most common alloying elements added to magnesium, zinc and aluminium show appreciable solubility while copper, nickel, tin and manganese appear to form insoluble intermetallic compounds. There is little detailed information extant on the effect of these metals on magnesium. All round improvements have been obtained by adding zinc or aluminium to magnesium together with or without small additions of other metals. Two such alloys have proved commercially successful—the American "Dow Metal"—an aluminium magnesium alloy—and the German "Elektron"—a zinc magnesium alloy. In the following tables a comparison is made between these two alloys with some well-known commercial engineering materials.

TABLE VII.—MECHANICAL PROPERTIES OF ALLOYS.*

| | Elektron. | | Dow Metal. | | Brass. | | Muntz Metal. | | Monel Metal. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cast. | Forged. | Cast. | Forged. | Cast. | Forged. | Cast. | Forged. | Cast. | Forged. |
| Elastic limit, tons per sq. in. ... | — | — | 1.0 | 4.6 | 4.0 | — | 6.5 | — | 17 | 20.6 |
| Yield stress, tons per sq. in. ... | 7 | 9 | 5.8 | — | — | 18.3 | 8.5 | 36.3 | — | 23.1 |
| Ultimate strength, tons per sq. in. | 9 | 20 | 11.1 | 21.4 | 13.6 | 22.5 | 29.3 | 41.4 | 37.0 | 43.4 |
| % Elongation ... | 5 | 18 | 4 | 7 | 39.2 | 7.8 | 22 | 4.25 | 44 | 42.4 |
| % Reduction of area ... ... | 2 | 14 | 3.5 | 6 | — | — | — | — | 68 | 62.0 |
| Brinell hardness | 46 | 68 | 55 | 71 | 51 | 176 | 96 | 173 | 136 | 166 |
| Impact value ... | — | 2.0c. | — | — | — | 17.4 | — | — | — | 74 (abt). |
| | 4.31 % Zn. 0.8 % Fe. | | 8 % Al. | | α Brass cold forging. | | αβ Brass hot forging. | | 60-65 Ni. 40-35 Cu. | |

| | Aluminium Bronze. | | Manganese Bronze. | | Mild Steel. | Nickel Ch. Steel Ready for service. | Dura-lumin. Forged and aged. | "Y" Alloy. Cast, heat treated | "Y" Alloy. Forged, heat and aged. | Silumin. |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cast. | Forged. | Cast. | Forged. | Normal-ised. | | | | | Cast. |
| Elastic limit, tons per sq. in. ... | — | — | 5.8 | 22.4 | — | — | — | — | 7.7 | 2.8 |
| Yield stress, tons per sq. in. ... | 11.6 | 42.0 | — | — | 22.4 | 53.8 | 15.3 | 7.5 | 15.0 | — |
| Ultimate strength, tons per sq. in. | 30.4 | 44.3 | 31.2 | 33.7 | 37.3 | 62.5 | 25.8 | 20.0 | 25.0 | 11.5 |
| % Elongation ... | 19.0 | 9 | 33 | 33.3 | 33 | 20 | 15.0 | 5 | 23 | 7.25 |
| % Reduction of area ... ... | 27 | 12 | 41 | 50.7 | 59 | 58 | 21 | — | 32 | 12 |
| Brinell hardness | 135 | 186 | 93 | 126 | 149 | 265 | 110 | — | — | 55 |
| Impact value ... | 26.8 | 5.9 | 21.0 | — | 15.8 | 20.4 | 24.5 | — | — | — |
| | 90 Cu 10 Al. | | αβ Brass. 0.2 % Mn. 1.5 % Fe. | | C=.33 % Mn. .50 % Si.=.22 % | Aero. 4.2 % Cu. C'shft. 0.7 % Mg. 1.5 Ni. 0.2 % Si. 0.8 Chr. | | 4 % Cu. 1.5 % Mg. 2.0 % Ni. 0.2 % Si. | | 13 % Si |

* Test data collected from various sources.

The mass-strength ratios of these materials have been arranged in order in Table VIII.

Data for the fatigue resisting qualities of these metals have been collected chiefly from H. J. Gough, *The Fatigue of Metals*, and the work of D. J. Macadam presented to the American Society for Steel Treating, in September, 1924. In the Table IX., the endurance limits of these materials in the forged condition is given together with the ratio of endurance limit to specific gravity.

A study of these tables shows that alloys of magnesium well merit consideration as materials for engineering construction. When the specific gravities of the materials are taken into account it is seen that the magnesium alloys are superior to the other well-known and largely used materials. This is especially striking in the case of high tensile steel. The high endurance weight ratio of the

magnesium alloys is an important advantage where reduction of weight is concerned and will appeal strongly to aircraft engineers.

TABLE VIII.—STRENGTH/WEIGHT RATIOS OF ALLOYS.

| Alloy. | Specific tenacity. | Mass/ strength. |
|---|---|---|
| Dow Metal, forged ... ... ... | 330 | 12.0 |
| Elektron, forged ... ... ... | 305 | 11.1 |
| Duralumin, forged ... ... ... | 254 | 9.2 |
| "Y" Alloy, forged ... ... ... | 223 | 8.1 |
| Nickel Steel, forged ... ... ... | 215 | 8.0 |
| "Y" Alloy, cast and heat-treated ... | 198 | 7.1 |
| Dow Metal, cast ... ... ... | 172 | 6.2 |
| Aluminium Bronze, forged ... ... | 162 | 5.9 |
| Muntz Metal, forged ... ... ... | 138 | 5.0 |
| Elektron, cast ... ... ... ... | 137 | 5.0 |
| Silumin, cast ... ... ... ... | 134 | 4.8 |
| Monel Metal, forged ... ... ... | 134 | 4.9 |
| Mild Steel, normalised ... ... | 130 | 4.7 |
| Monel Metal, cast ... ... ... | 116 | 4.2 |
| Aluminium Bronze, cast ... ... | 112 | 4.0 |
| Manganese Bronze, forged ... ... | 107 | 3.9 |
| Manganese Bronze, cast ... ... | 99 | 3.6 |
| Muntz Metal, cast ... ... ... | 97 | 3.5 |
| Brass, forged ... ... ... ... | 74 | 2.7 |
| Brass, cast ... ... ... ... | 45 | 1.6 |

TABLE IX.—FATIGUE RESISTING VALUES OF ALLOYS.

| | Endurance limit, tons per sq. in. | Endurance limit/specific gravity. |
|---|---|---|
| Elektron ... ... ... | ± 7.6 | 4.2 |
| Duralumin ... ... ... | ±10.5 | 3.7 |
| "Y" Alloy ... ... ... | ±10.2 | 3.7 |
| Nickel Steel ... ... ... | ±28.4 | 3.6 |
| Mild Steel ... ... ... | ±17.5 | 2.2 |
| Aluminium Bronze ... ... | ±15.6 | 2.1 |
| Monel Metal ... ... ... | ±16.4 | 1.8 |
| Muntz Metal ... ... ... | ±12.5 | 1.5 |
| Manganese Bronze ... ... | ± 8.3 | 1.0 |
| Brass (alpha) ... ... ... | ± 7.6 | 0.9 |

Many factors must be taken into account in comparing the relative merits of any alloys for use as structural materials for aircraft. A. J. Sutton Pippard* has examined two factors—weight and flexibility.

Let $f$ = proof stress—stress which produces a specified permanent set after being imposed for a certain time.
$\rho$ = specific gravity.
$E$ = modulus of elasticity.
$p$ = ratio of specific gravities of two metals, A and B,
$= \rho_a/\rho_b$.
$q$ = ratio of moduli of elasticity
$= E_a/E_b$.

* Note on the Comparison of Metals as Aeroplane Structural Materials, Aeronautical Research Committee No. 729 (M.3).

The conditions for equal weight and strength in aeroplane structural members built in two metals A and B are:—

(1) Beams, *e.g.*, certain bays of the spars,

$$f_a = pf_b \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

(2) Struts, *e.g.*, fuselage struts, interplane struts (if windage is neglected),

$$p = q \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

(3) Laterally loaded struts or ties. The main plane spars afford the best example of this:—

$$f_a/f_b = p\{1/(1-P/Qa)+K\} \quad [1/(1-q/p\{P/Qa\})+K] \quad . \quad (3)$$

when $P$ is the axial load.

$Q$ is the Euler failing load of the member.

$K$ is a constant.

(4) The condition for equal strength and flexibility is

$$f_a = qf_b \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

In the report a comparison was made of steel and duralumin and the following results were given:—

(*a*) For strut members steel and duralumin give very nearly the same weight for strength ratio.

(*b*) For all beams, whether simple or subjected to axial loads, steel with a proof stress greater than 45 tons per square inch is necessary for the construction of a lighter member than duralumin.

(*c*) Steel with a proof stress of 45 tons per square inch gives the same flexibility as duralumin. Higher proof stresses will allow more flexibility.

The application of these results for a comparison of the newer magnesium alloys is very interesting, especially in view of the fact that elektron has been already extensively used in Germany for aircraft construction.

### *Comparison of Steel with Elektron*

Assuming for steel $\rho_a = 7.9$

$E_a = 13{,}000$ tons per sq. inch.

Assuming for elektron $\rho_b = 1.81$

$E_b = 2{,}900$ tons per sq. inch.

$f_b = 14.6$ ,, ,,

then $p = \rho_a/\rho_b = 4.36$

$q = E_a/E_b = 4.48$

(*a*) Members subjected to pure bending: From equation (1) $f_a = pf_b = 63.66$, *i.e.*, to compare with elektron steel must have a proof stress of at least 64 tons per square inch.

(*b*) Members subjected to compression: From equation (2) the condition for equal weight and strength is $p = q$. For the two materials, steel and elektron, this condition is almost exactly fulfilled, *i.e.*, for strut members steel and elektron are equally good on the weight for strength basis.

(*c*) Members subjected to combined bending and compression: Since $q/p$ is so nearly equal to unity, equation (3) reduces to $f_a = pf_b$, *i.e.*, the same as for pure bending. Hence, as before, the steel must have a proof stress of at least 64 tons per square inch to render it as efficient as elektron on the weight comparison.

(*d*) Comparison of flexibility: From equation (4) $f_a = qf_b = 63.5$ tons per square inch, *i.e.*, steel with a proof stress of 64 tons per square inch gives as flexible a structure as elektron. Higher proof stresses will allow more flexibility.

To summarise: (*a*) For strut members steel and elektron give very nearly the same weight for strength ratio; (*b*) for all beams, whether simple or subjected to axial loads, steel with a proof stress greater than 64 tons per square inch allows the construction of a lighter member than elektron; (*c*) steel with a proof stress of 64 tons per square inch gives the same flexibility as elektron.

### *Comparison of Duralumin with Elektron*

Assuming for duralumin $\rho_a = 2.80$
$E_a = 4{,}700$ tons per sq. inch.
,, ,, elektron $\rho_b = 1.81$
$E_b = 2{,}900$ tons per sq. inch.
$f_b = 14.6$ ,, ,,

On calculation it can be shown that to equal elektron, duralumin must have a proof stress of at least 23 tons per square inch. The following is a summary of the results: (*a*) For strut members duralumin and elektron give very nearly the same weight for strength ratio, the advantage, if any, being with elektron; (*b*) for all beams duralumin must have a proof stress of at least 24 tons per square inch if a duralumin structure is to be built which is to be lighter in weight than elektron; (*c*) to build a duralumin structure which shall be as flexible as one built from elektron, the duralumin must have a proof stress as high as 24 tons per square inch.

It is necessary to use a larger volume (though a smaller weight) of metal to secure the same strength when using light alloys. This is in some cases an advantage. The rigidity of a component part of a structure depends upon the moment of inertia of the system which is controlled by the dimensions of the part and not by either its weight or its strength. The greater the dimensions of a part the greater its moment of inertia and consequently the rigidity of the structure. This is readily obtainable, in fact automatically so, by the use of light alloys. As the necessary strength can be obtained by the use of magnesium alloys without the use of too much weight, *i.e.*, the mass/strength ratio are high the use of these alloys presents definite advantages.

### *The Zinc Magnesium Alloys*

Zinc shows appreciable solubility in magnesium. Solid solutions occur up to a zinc content of about 7 per cent., beyond which an insoluble compound $Mg_2Zn$ of density 5.126 appears, resulting in brittleness. Beyond 8 per cent. zinc the maximum strength falls from 11 tons per square inch to 7.5 tons at 12 per cent. zinc. The properties of the cast alloy are given in Table X.

TABLE X.—ZINC MAGNESIUM ALLOYS, ONE INCH DIAMETER CHILL CAST BARS.

| % Zinc. | Ultimate stress, tons per sq. in. | % Elongation. | Specific gravity. |
|---|---|---|---|
| 4 | 5·5 | 3 | 1.78 |
| 5 | 6.0 | — | 1.79 |
| 6 | 7·7 | — | 1.81 |
| 7 | 9·4 | — | 1.82 |
| 8 | 11.0 | 6 | 1.84 |
| 9 | 9·5 | — | 1.85 |
| 10 | 8.0 | 2 | 1.87 |
| 11 | 7·7 | — | 1.89 |
| 12 | 7·4 | 2 | 1.90 |

Very little information on the properties of forged zinc magnesium alloys has been published. Aitchison gives the following figures of the forged 3 per cent. zinc alloy of specific gravity 1.77: Maximum stress 13.9 tons per square inch

and an elongation of 9 per cent. The zinc magnesium alloys do not appear to be used to much extent.

### *The Aluminium Magnesium Alloys*

These alloys have been used extensively and a fair amount of information has been published on their properties. The constitution of these alloys was revised by Hanson and Gayler,[5] whose equilibrium diagram leaves little to be desired. From this diagram magnesium at the ordinary temperatures holds about 9 per cent. of aluminium in solid solution. Beyond this a compound $Mg_3Al_2$ appears forming a eutectiferous series with the solid solution up to about 60 per cent.

The properties of these alloys are given in the following tables:—

TABLE XI.—ALUMINIUM MAGNESIUM ALLOYS, CHILL CASTINGS,* ONE INCH DIAMETER BARS.

| % Al. | Max. stress, tons per sq. in. | Elongation % | Specific gravity. |
|---|---|---|---|
| 0 | 7·5 | 6 | 1.74 |
| 2 | 7·1 | 6 | 1.75 |
| 4 | 6.9 | 4 | 1.76 |
| 6 | 11.0 | 7 | 1.77 |
| 7·5 | 9·5 | 4 | 1.78 |
| 11.0 | 9.0 | 1 | 1.79 |
| 12.5 | 6.2 | 0 | 1.82 |

* L. Aitchison, Institute Automobile Engineers, 1924, XVIII., 557-591.

TABLE XII.—ALUMINIUM MAGNESIUM ALLOYS,† SAND CASTINGS.

| % Al. | Limit of proportionality, tons per sq. in. | Max. stress, tons per sq. in. | Elongation, % on 2in. | Brinell hardness No. | Specific gravity. |
|---|---|---|---|---|---|
| 4 | 1.1 | 11.1 | 9 | 42 | 1.77 |
| 6 | 0.9 | 10.7 | 7 | 46 | 1.78 |
| 8 | 0.9 | 9.0 | 2 | 53 | 1.79 |
| 10 | 1.1 | 8.4 | 1 | 57 | 1.81 |
| 11 | — | 9.0 | 1 | — | — |
| 12 | 2.0 | 8.4 | 0.5 | 65 | 1.82 |

† S. L. Archbutt, *The Metallurgist* (supplement to *Engineer*, 1926, II., 4-6, 26-30.

TABLE XIII.—ALUMINIUM MAGNESIUM ALLOYS, FORGED BARS.

| % Al. | Limit of proportionality, tons per sq. in. | Max. stress, tons per sq. in. | Elongation, % on 2in. | Reduction of area % | Proof Stress. | Brinell hardness. |
|---|---|---|---|---|---|---|
| 4 | 3·3 | 18.3 | 8.5 | — | 4.6 | 61 |
| 6 | 2.4 | 18.3 | 16.0 | 21 | 6.5 | 54 |
| 8 | 4·7 | 20.5 | 9.0 | 12 | 7·0 | 59 |
| 10 | 3·1 | 21.0 | 8.0 | 10 | 6.3 | 68 |
| 12 | 4·7 | 20.1 | 7·5 | 8 | 6.6 | 71 |

TABLE XIV.—ALUMINIUM MAGNESIUM ALLOYS, FORGED AND HEAT-TREATED BARS.

| % Al. | Limit of proportionality, tons. per sq. in. | Max. stress, tons per sq. in. | Elongation, % on 2in. | Reduction of area, %. | Proof stress. | Brinell hardness. |
|---|---|---|---|---|---|---|
| 6 | 3·5 | 18.3 | 10.0 | 10 | 6.3 | 53 |
| 8 | 3·5 | 21.0 | 4.0 | 4 | 6.5 | 68 |
| 10 | 4.0 | 24.5 | 2.0 | 2 | 6.5 | 83 |
| 12 | 6.0 | 20.1 | 1.0 | 1 | 7·4 | 90 |

[5] *Journal Institute of Metals*, 1920, II., 201.

These figures are the best which have been recorded up to the present.

As regards strength these alloys show remarkable possibilities, and in the forged condition values are obtained which are equal to those of best quality wrought iron with very small increases in specific gravity over pure magnesium. Unfortunately their ductility is low, but probably in the near future some special method of forging and heat-treatment will be devised to increase these properties. The limit of proportionality is very low for the cast and forged bars, but this is counterbalanced by the relatively high proof stress. It is interesting to note that with more than about 9 per cent. aluminium there is a general decrease in the values of the mechanical properties. This is due to the increasing amount of insoluble compound present in the alloys. The best all round alloy is that containing 6 per cent. aluminium, which has been already found useful for many purposes and is to be recommended as a piston alloy. Aitchison[6] gives the following data for this alloy:—

TABLE XV.—PROPERTIES OF 6 PER CENT. ALUMINIUM MAGNESIUM ALLOY.

| | |
|---|---|
| Specific gravity ... ... ... ... ... ... | 1.76 |
| Modulus of elasticity, tons per sq. inch ... ... ... | 2850 |
| Modulus of elasticity/specific gravity, tons per sq. inch | 1620 |
| Maximum stress at 15°C. ... ... ... ... ... | 11.0 |
| Maximum stress at 15°C. specific gravity ... ... | 6.2 |
| Maximum stress at 250°C. ... ... ... ... ... | 5.6 |
| Maximum stress at 350°C. ... ... ... ... ... | 4.6 |
| Coefficient of thermal expansion ... ... ... ... | 0.0000256 |
| Thermal conductivity (c.g.s.) ... ... ... ... | 0.180 |
| Shrinkage, inches to 1 foot length ... ... ... | 0.14 |
| Melting point, °C. ... ... ... ... ... ... | 550 |

### *Copper Magnesium Alloys*

These alloys are being investigated in some detail by the Author and W. T. Cook, B.Sc. A report of the properties of the chill cast bars has been already published.[7] Copper is almost completely insoluble in magnesium and forms an insoluble compound $Mg_2Cu$. In magnesium containing 0.06 per cent. copper the presence of the compound is readily seen under the microscope. On increasing the amount of copper the tensile strength is increased up to about 2.5 per cent. copper, beyond which the strength decreases. The ductility is at once decreased on the addition of copper and becomes almost negligible beyond 6 per cent. No authoritative detailed results have yet been published on the properties of the forged alloys. The properties of chill cast bars are given in the following table:—

TABLE XVI.—COPPER MAGNESIUM ALLOYS, CHILL CAST BARS.

| % Copper | Limit of proportionality, tons per sq. in. | Ultimate stress tons per sq. in. | Elongation, % on 2in. | Reduction of area, % | Brinell hardness (10mm. 500kg.). | Specific gravity. |
|---|---|---|---|---|---|---|
| traces | 0.6 | 7.4 | 7.0 | 5.4 | 30 | 1.75 |
| 1.15 | 1.6 | 8.2 | 6.2 | 3.9 | 39 | 1.76 |
| 1.88 | 2.0 | 9.7 | 3.3 | 3.5 | 40 | 1.77 |
| 2.83 | 2.5 | 7.7 | 2.3 | 2.8 | 40 | 1.78 |
| 3.96 | 2.6 | 6.7 | 2.0 | 2.2 | 43 | 1.80 |
| 4.59 | 2.9 | 7.0 | 1.8 | 1.8 | 44 | 1.81 |
| 5.25 | 3.0 | 7.3 | 1.6 | 1.3 | 44 | 1.82 |
| 6.31 | 3.5 | 7.8 | 0.75 | 1.0 | 45 | 1.84 |
| 7.69 | 3.2 | 7.82 | 0.2 | 0.3 | 50 | 1.86 |
| 9.84 | — | 7.00 | nil | nil | 55 | 1.87 |

[6] *Loc. cit.*
[7] *Loc. cit.*

It is hoped that further work will be published soon on the properties of forged copper magnesium alloys.

Speaking generally of the properties of binary magnesium alloys, it appears that the optimum all round properties are obtained with 92—97 per cent. magnesium. At present the chief disadvantage is the low ductility. The alloys compare most favourably with binary aluminium alloys and in many cases are superior.

Of the alloys which have already found fairly extensive use, two are important—" Dow Metal " and " Elektron."

### *Elektron*

Zinc is the predominating alloying element of " Elektron," many samples of which are merely zinc magnesium alloys containing up to 5 or 6 per cent. zinc. The majority of elektrons, however, contain small percentages of other metals such as copper, aluminium and iron. Elektron is the " duralumin " of magnesium alloys and its composition and properties vary within fairly wide limits. Recent technical literature gives numerous test data of elektron.[8]

Elektron is a German product and was first introduced in 1909 by the Chemische Fabric Griesheim-Elektron, Frankfort-on-the-Main. It was used extensively by the Germans during the war in the manufacture of aircraft, especially the Zeppelins. The following is the range of its properties[9]:—

TABLE XVII.—MECHANICAL PROPERTIES OF ELEKTRON.

| Condition. | Specific gravity. | Tensile strength, tons per sq. in. | Elongation /. | Brinell No. |
|---|---|---|---|---|
| Castings, all kinds ... ... | 1.82 | 10—11.5 | 4—6 | 45 |
| Castings ... ... ... ... | 1.82 | 12.5—14 | 8—10 | 45 |
| Pressed goods (rods, tubes, shapes, sheets, wire) ... | 1.81 | 16.5—18 | 15—18 | 48 |
| Pressed parts (sunk) ... | 1.78 | 16—16.5 | 8—10 | 45 |
| Pressed (various) ... ... | 1.82 | 21.5—23 | 7—8 | 75 |
| Pressed and heat treated ... | 1.82 | 21.5—23 | 10—12 | 69 |
| Pressed and heat hardened | 1.82 | 26.5—28 | 3—5 | 90 |

Moore[10] gives the results of tests on forged elektron having the following percentage composition:—94.72 magnesium, 4.31 zinc, 0.24 silicon, 0.25 iron, 0.41 copper:—

| | |
|---|---|
| Limit of proportionality, tons per square inch ... ... ... | 2.8 |
| Ultimate strength, tons per square inch ... ... ... ... | 16.3 |
| Elongation, per cent. ... ... ... ... ... ... ... | 18 |
| Reduction of area, per cent. ... ... ... ... ... ... | 21 |
| Brinell hardness No. ... ... ... ... ... ... ... | 64 |
| Scleroscope hardness number ... ... ... ... ... ... | 19 |
| Impact value (Charpy) ... ... ... ... ... ... ... | 2.9 |
| Static torsion limit of proportionality, tons per square inch ... | 1.8 |
| Static torsional strength (modulus of rupture), tons per square inch | 11.0 |
| Endurance limits (reversed bending stresses), tons per square inch | 7.6 |

On similar material containing in addition 1.6 per cent. aluminium, Aitchison[11] obtained the following results on extruded bars:—

[8] *Loc. cit.*
[9] Schmidt, *Deutsche Bergwerks Zeitung.*
[10] R. R. Moore, " The Endurance Limits of Non-Ferrous," *Proc. A.S.T.M.*, June, 1923.
[11] Aitchison, *Journal Institute of Metals*, 1923, Vol. XXIX.

| | Round bars, 1¼in. diam. | Rectangular bar, 1⅛in. x ⅝in. |
|---|---|---|
| Elastic limit, tons per sq. in. ... ... | 4.4 | 6.4 |
| Proof stress, ,, ,, ... ... | 14.6 | 11.3 |
| Maximum stress, ,, ,, ... ... | 17.6 | 16.1 |
| Elongation per cent (on $l = \sqrt[3]{\text{area}}$) ... | 11.0 | 12.5 |
| Reduction of area per cent. ... ... ... | 13.4 | 16.3 |

Beckinsale[12] records similar results of tests on three extruded samples of German origin.

The following results were recently obtained on material having a percentage composition of 5.1 zinc, 0.93 copper, 0.06 iron, 0.06 silicon. The alloy was cast in chill moulds 1 inch and 2¼ inches diameter. The larger ingot was then forged at a temperature of 420°C. under a steam hammer to 1in. diameter rods.

| | Cast. | Forged. |
|---|---|---|
| Limit of proportionality (tons per sq. inch) ... | 2.9 | 3.7 |
| Maximum stress (tons per sq. inch) ... ... | 8.5 | 18.6 |
| Elongation per cent. on 2in. ... ... ... | 6 | 19 |
| Reduction of area per cent. ... ... ... | 4.5 | 22 |
| Brinell hardness number ... ... ... | 49 | 58 |
| Specific gravity ... ... ... ... ... | 1.80 | 1.81 |
| Mass/density ratio ... ... ... ... | 4.7 | 10.3 |
| Specific tenacity ... ... ... ... ... | 130.4 | 284 |

### *"Dow Metal"*

The aluminium magnesium alloys have been exploited by the Dow Chemical Co., of Midland, Michigan, under the term "Dow Metal." E. J. Jenkins[13] gave the properties of this alloy as follows:—

| | |
|---|---|
| Specific gravity ... ... ... ... ... ... | 1.79 |
| Tensile strength, tons per sq. inch ... ... ... | 9.9—11.2 |
| Yield point, tons per sq. inch ... ... ... ... | 5.4— 6.3 |
| Compressive strength, tons per sq. inch ... ... | 20.1 |
| Elongation per cent. on 2in. ... ... ... ... | 3.5 |
| Reduction of area ... ... ... ... ... ... | 3.5 |
| Modulus of elasticity, tons per sq. inch ... ... | 4018 |
| Brinell hardness number ... ... ... ... ... | 55—75 |
| Heat conductivity (Cu = 1,000, cast iron 0.108) ... | 0.295 |
| Coefficient of linear expansion from 0—800°F. ... | 0.000028 |

This alloy has been used as a piston alloy in a Ford motor with very satisfactory results. The best compositions advocated are from 6—12 per cent. aluminium. The alloys[14] are greatly improved by correct heat treatment, consisting of absorbing the compound $Al_2Mg_3$ in solution, cooling rapidly and then reheating to 150°—250°C. to allow the compound to precipitate in a fine state of division which causes a gradual hardening and increase in strength.

Vickars,[15] writing on "Dow Metal," states that by heat-treatment sand castings have a tensile strength of 13 tons per square inch or more with an elongation and reduction of area increased up to 6 per cent. When drop-forged the strength reaches over 22 tons per square inch with a Brinell hardness number of over 70. The main use found for the alloy has been in the manufacture of pistons and connecting rods for automobile, airplane and motor boat engines. It is the lightest material that can be used for such a purpose. The claim is made that this alloy differs from aluminium in that there is no permanent growth or set at the working temperature of a piston of an internal combustion engine.

[12] Beckinsale, *Journal Institute of Metals*, 1921, Vol. XXVI.
[13] *The Iron Age*, 1920, Vol. VI., p. 193.
[14] Stoughton and Miyake, *Amer. Inst. Mech. Eng.—Inst. of Metals Division*, 1926.
[15] *Metals and Their Alloys*, p. 629.

### *Founding of Magnesium and Its Alloys*

Magnesium is chemically a very active element, especially so at elevated temperatures, and in the molten condition will combine with the majority of other substances, and is capable of dissolving large quantities of gases which come out of solution when the melt solidifies. Consequently it is by no means an easy matter to obtain sound castings in a manner which can be carried out readily in any works. The metal must be melted in a steel or iron crucible, as the use of a clay crucible causes contamination of the melt with silicon, and the use of graphite crucibles is not possible on account of carbide formation. The chief difficulties are the formation of relatively large, smooth-walled gas cavities and inclusions of slag formed by the use of flux which is necessary to prevent excessive oxide formation. The gas originates in the molten metal from three sources: (1) By mechanical entanglement between pieces of the charge, (2) solution from the furnace atmosphere, and (3) carbide formation and its subsequent decomposition on solidification of the metal.

The Author and his colleague have carried out a great deal of experimental work on the production of sound castings and have succeeded in being able to produce absolutely sound ingots up to four inches diameter, free from gas holes, slag inclusions, contamination of the melt with iron or silicon, and with complete freedom from burning.[16] No "dope" of any kind has been used and the method can be carried out in any foundry desiring to cast these ultra-light alloys. The method recommended is as follows:—A bottom pouring forged steel crucible is "broken in" by forming on the internal surface a skin of magnesium or a magnesium rich iron alloy by melting scrap metal in it for some hours. In this way no iron from the crucible, stopper or stirrer goes into the melt.

The advantages of bottom pouring are: (1) The melt does not pass through a layer of slag and flux on teeming with the result that metal with few if any inclusions is obtained; (2) the lid can be made tightly fitting, and is not removed either during melting or teeming, thereby minimising oxidation and loss; 3—4 per cent. of the weight of metal melted of a mixture of anhydrous magnesium chloride and fluoride is a satisfactory flux. This flux is very deliquescent and is best fused immediately before charging the crucible. The slag left is also deliquescent and gives a distinct smell of ammonia and acetylene, due to the formation of nitrides and carbides during the melting. After a melt is teemed the crucible should be scraped and cleaned immediately. The melting loss must be kept as low as possible, inasmuch as with a high loss the impurities, *e.g.*, iron and silicon, are concentrated in the metal. The melting loss can be kept to a minimum by using sufficient, but not too much, flux and by the avoidance of over-heating or soaking the metal. With satisfactory melting practice the loss should not exceed 0.5—0.75 per cent.

The colour of the ingot or casting is yellowish instead of white if the temperature has been too high or prolonged soaking has taken place. The crucible, stopper, stirrer and lid are made red hot and thoroughly cleaned and charged while black hot so that no moisture is present. Any trace of moisture in the metal, flux or crucible will result in unsound castings. The alloying elements may be added as previously cast rich alloys or hardeners. The hardener is added near the centre of the charge and the flux distributed at regular intervals. When the crucible is charged the lid is put on tightly.

The melting operation can be conveniently carried out in an upright circular gas furnace. When melting is complete, as judged by the sinking of the stirrer to the bottom of the crucible, the metal is thoroughly stirred to incorporate the flux in the molten metal. The gas supply is turned off and the crucible allowed

[16] W. T. Cook and W. R. D. Jones, *Journal Institute of Metals*, Vol. XXXVI., 1926.

to cool reasonably slowly. When freezing is complete the gas supply is turned on again and the metal remelted as rapidly as possible. Stirring is not again resorted to in order that the metal shall not be contaminated with flux and slag. The gas supply is lowered and the pot allowed to remain at rest for a few minutes. The pot is then taken from the furnace and teemed into the mould placed an inch or so below.

For chill castings the moulds of forged steel or cast iron should have a smooth polished finish, showing no tool marks, as it was found that a number of failures which occurred during machining and a number of irregular test results were traced to small internal cracks in the bars which appeared to have been developed by stresses set up during solidification owing to the metal being gripped by rough tool marks. A slight taper on moulds larger than about $1\frac{1}{4}$ inches diameter was found to be beneficial.

Moulds are preheated to a temperature higher than that generally used and a proved temperature is between 350° and 400°C. Using lower temperatures there is a great risk of cold shut. No mould dressing is necessary. Moulds of about 1 inch and less in diameter are best poured when inclined about 45°. larger diameter moulds can be teemed in an upright position. The melt should always be teemed slowly on the tip of the mould near the top and should be somewhat on the sluggish side. There should be no interruption of the continuity of the metal stream or cold shutting will occur. For sand castings a hard baked mould should be used and the core oven run at a higher temperature than usual, *i.e.*, about 400°C. The sand should have a high percentage of silica and so be low in materials likely to loose combined water at about 700°C.

The moulds and cores should not be removed from the ovens until immediately before teeming. If they happen to have cooled down then they must be put back into the oven in case the sand should have re-absorbed moisture during cooling. No mould dressing is necessary. If permanent moulds can be used then they will in all probability prove eminently satisfactory for these alloys.

Gates should be as small as possible consistent with a free flow of the metal. These alloys necessarily require a larger head of metal than other alloys to produce the same pressure and the length of the runner should be at least half as much again as that used in aluminium alloy castings. Castings can easily be obtained with an excellent silvery skin and there is no tendency for sand to stick to the surface. The surface can be cleaned from sand or white oxide by wire brushing. Castings can be given a beautiful finish by a momentary dip in strong nitric acid or dilute hydrochloric acid and immediately rinsing in running water. This practice is not recommended for general use.

The forging of alloys containing from 85-90 per cent. magnesium is easily performed by rolling, extruding, drawing and hammering and drop forging with a general improvement in the mechanical properties. The best general forging temperatures are from 410°C.-450°C. Above this temperature there is the liability to burn, and below 400°C. there is a strong tendency to cold shortness. The billets should be heated and soaked at the temperature in a gas furnace free from the possibility of flames impinging on the bars and under pyrometric control. The best practice the Author considers is to use a muffle furnace heated to a constant temperature of 420°C. $\pm 5°$, then to place the billets inside, and after the temperature has again reached 420°C. to allow the bars to soak for one hour.

The specific heat of magnesium being relatively high the time taken for the bars to reach the forging temperature is greater than usual. For forging down under the steam hammer the tools should all be at about 400°C. Pure magnesium and alloys containing up to 2 per cent. alloying element can generally be forged from $2\frac{1}{2}$ inches diameter down to 1 inch without reheating.

The greater the amount of alloying element the harder the alloy and more reheatings required. A little experience will soon enable the workman to gauge when the alloy is too cold and requires reheating. Magnesium alloys, if forged within the correct limits of temperature, will withstand "brutal" treatment. Sound forged bars will emit a pleasing ring which can be used as a rough guide for their soundness.

Magnesium alloys are readily machined and give a brilliant finish. There is little appreciable difference between the behaviour of the pure metal and the relatively hard alloys. Long turnings are not desirable, since being light and feathery, they tend to collect near the tool point, obscuring and fouling the cutting edge. The tool should be given a fair amount of lip in order that the turnings should be broken into short lengths. Centre holes should be carefully and accurately drilled and well greased with a thick grease. The bar should be held neither too lightly nor too loosely. Unless these precautions are taken the centre holes will wander or the lathe centre will "bed down" into the centre hole, developing much friction and heat, causing the bar to expand considerably.

Magnesium alloys can be machined at very high speeds with a depth of cut limited only by the diameter of the bar necessary to withstand the bending stresses set up and there is no need for lubrication. The alloys can be readily screw cut, tapped, drilled, reamed and sawn and will take a brilliant polish.

Magnesium alloys will not readily corrode in the atmosphere and are quite as resistant as aluminium alloys. Freshly exposed pieces have a brilliant surface which becomes dull owing to the formation of a thin film of oxide or hydroxide which prevents further corrosion. A few years ago the commercial metal was relatively a poor material containing numerous particles of flux, chiefly chlorides. These particles caused localised corrosion and excessive pitting. Present day metal is free from these defects. Ingots and castings should, however, be cleaned free from any adhering slag or flux as soon as possible, otherwise local corrosion becomes intense. In assembling structural members contact with brass screws or rivets must be avoided on account of galvanic action being set up, leading to corrosion. Screws or rivets of the same or similar material must be used. Rivets should be heated to 450°C., when they can be readily upset and give a tight-fitting joint. Joints should not be soldered but made by screws, rivets or, if necessary, welded by the oxyhydrogen flame. The alloys can be ground for metallographic examination by using the ordinary French emery papers flooded with paraffin oil and polished by means of "Globe" polish on selvyt cloth, the last traces of polish being removed before etching by means of water-free acetone. A satisfactory etching reagent is an alcoholic solution of 1 per cent. nitric acid with 0.5 per cent. hydrochloric.

Some of the chief uses for these alloys are: (1) Instruments to which they give lightness combined with strength. These alloys are especially useful in the case of portable instruments and artificial limbs; (2) constructional members in aircraft construction. They give rigidity combined with lightness and have been used for the framework of dirigibles, and can also be used in the form of thin sheet for casing. Thin sheets having a tensile strength of 25 tons per square inch are readily obtainable; (3) piston metals for internal combustion engines.

The most authoritative account of pistons and connecting rods is that given by L. Aitchison.[17] Dr. Aitchison states that for cast pistons in light alloys the choice appears to be between the 8 per cent. copper aluminium alloy and the 6 per cent. aluminium magnesium alloy and where weight is of supreme importance the latter material has the advantage. The use of magnesium alloys for pistons has had a great deal of advertisement from the results of a com-

[17] "Light Alloys for Pistons and Connecting Rods," L. Aitchison, D.Met., *Proceedings Institution of Automobile Engineers*, 1914, XVIII., 557-591.

petition initiated by the German Government in 1922 at the Technical University of Berlin under the direction of Professor G. Becker. Sixteen sets of pistons were machined to suit a 45 horse-power Daimler lorry engine and a similar set to suit a 10-30 horse-power Protos car engine. The tests were run on laboratory testing beds and were undertaken to supply information as to life, durability, reasonable wear and tear. compression ratios, hardness, thermal expansion and absorption. Die-stamped magnesium pistons containing 13.5 per cent. copper and 0.3 per cent. silicon was placed first and one containing 12 per cent. aluminium placed fourth.

Aluminium and its alloys have been largely used as piston metals owing to their high thermal conductivity rather than to any small saving in weight and have resulted in increased thermal efficiency. Several magnesium alloys have now been produced as good as aluminium alloys if not superior in those properties requisite for a good piston with a saving of about 40 per cent. in weight.

Pistons made from magnesium by reason of their lower specific gravities enable the walls and crown to be made thicker, further assisting cooling and also reducing the inertia loads on the bearings. A magnesium piston may have twice the cross-sectional area of a corresponding cast iron piston and yet we only have the weight. Further advantages of magnesium over aluminium for this purpose are the fact that magnesium pistons do not "grow" in use, and require very little more clearance than cast iron pistons. Pistons are now being made from substantially pure forged magnesium treated by the Michel process, which causes the metal to become fibrous and the grain structure to follow the contour of the piston thereby increasing its thermal conductivity and resulting in a cooler—almost self-cooling piston. These forged pistons are manufactured by the Maxium Company and are exceedingly light and tough.

Another important point is that the specific heat of magnesium and its alloys is high and so reduces the rise in working temperature. This fact together with the high thermal conductivity and the greater cross-sectional area permissible lessens the risk of high temperatures prevailing so that the lubricating oils are not decomposed and there is less likelihood of carbon deposition. Fouling and seizing are thereby minimised; (4) There are great possibilities in the use of magnesium alloys for electrical purposes. For equal pressure drop the weight of a magnesium alloy such as elektron needed for transmitting a given current is half that of copper and about 95 per cent. that of an aluminium conductor. That is to say magnesium alloys are twice as efficient weight for weight as copper for electrical conduction. Elektron is used largely in Germany for trolley wheels of electric cars.

The thin film of oxide or hydroxide formed on magnesium not only serves to prevent further corrosion, but acts as a fairly good electric insulator—a layer of 0.1 mm. thick will withstand 220 volts. This film can be increased in thickness by heating the wire in steam under a high pressure for some time. If the wire is then heated at about 320-330°C the hydroxide breaks down to crystalline magnesium, which is a superior insulator. Thus treated the wire may become important in connection with the manufacture of transformers and for electric insulating purposes. The insulating surface will conduct heat away more efficiently than will the ordinarily used cotton or silk covered copper wire.

## Discussion

Mr. Manning, before opening the discussion, read the following written contribution from Colonel the Master of Sempill: "We can most certainly congratulate Mr. Jones on his paper, which contains a great amount of very valuable information, not only on the properties of the finished product, but on some of those many factors which go towards the successful production of these various alloys.

"The question of metal aircraft has in this country at least resolved itself into a discussion of the relative merits of steel and the various light alloys. The advantages of the one over the other can hardly be discussed from consideration of the physical qualities of the material alone. There are other economic questions which come into the picture, and one of these questions which have been advanced by those who favour the use of steel is that this country is essentially a steel producing country and does not offer to any considerable extent supplies of raw material for the manufacture of the light aluminium alloys. It seems, however, that it is possible that such supplies as do exist have not been fully exploited, but it is at the same time doubtful as to whether full exploitation would meet our requirements did the use of light alloys become general. From personal investigations made at factories in Germany and France, where aluminium alloys are very largely used, one is struck by the apparent advantage of this material over steel during manufacture, in that members are more robust and not so liable to distortion during the process of assembling, as is the case with the very thin sections that are used in the manufacture of steel aircraft.

"Mr. Jones quotes a statement by Mr. R. J. Anderson, obviously a very great enthusiast for metal construction. Although this statement is no doubt correct in a large measure, it does not seem likely that we shall ever completely do away with the wooden machine, although the tendency is towards the greater employment of metal in certain parts of such machines. I think, however, that the statement of Anderson that 'fire hazard is exceptionally dangerous with doped linen' is not quite in accordance with the facts and is liable to give an unnecessary sense of danger to those who must obviously use machines so covered for very many years to come. The further statement, too, that metal aircraft will be practically free from fire hazard, which generally occurs after a crash, is perhaps too broad a claim, judged from the happenings in America.

"I note with interest that according to Mr. Jones magnesium alloys can be machined dry at high speeds and with heavy cuts, which seems rather at variance with earlier experiences. I would like to obtain his views on the machining of other of the light alloys. I should also like to ask as to whether Mr. Jones has investigated the various means of preventing corrosion due to the action of sea water, such, for example, as the anodic process. His views on this very important point and suggestions as to future lines of research would be valuable."

Wing Commander CAVE-BROWNE-CAVE said: We are greatly indebted to Mr. Jones for his paper and for his lucid verbal description. There are, however, certain points in the paper which he did not refer to verbally.

He quotes Mr. Anderson as saying that "Fire hazard is exceptionally dangerous with doped linen." That is not correct for modern wing fabric. (Wing Commander Cave placed a lighted match on a piece of doped linen fabric and allowed it to burn out, producing only slight charring of the fabric. He then held the fabric vertically and lit the bottom corner, showing that flame was maintained but was extinguished by the least puff of wind.) Perhaps magnesium foil of the same weight per square foot would be more easily ignited. Once magnesium is ignited it produces so much heat that it is almost impossible to extinguish.

The inflammability of magnesium structure of an aeroplane is of comparatively little importance so long as petrol is used. When petrol has been displaced by heavy oil, the existence of a comparatively inflammable magnesium structure would constitute a very serious disadvantage.

Mass strength is not satisfactorily defined in the paper. Specific tenacity is defined as the tensile strength in tons/sq. in. divided by the weight per cubic inch. The unit of it is the quite arbitrary one of 2,240 inches. The same quality is

far better expressed as the breaking length, *i.e.*, the length of a uniform wire which will just break under its own weight. He had used this method in early airship design and had been interested to find that best quality hemp cord had a breaking length of 27,500 metres, as compared with forged duralumin 14,400 and 100-ton steel 20,600 metres. The figures given in Table VIII. for forged Dow metal were equivalent to a breaking length of 19,000 metres.

The paper states that the corrosion of magnesium alloys in air is not more rapid than that of aluminium alloys. In the presence of sea water or salt air it was at present so rapid as to constitute a very serious disadvantage. He had it on first hand information that the magnesium crankcase of Captain Biard's Schneider Cup seaplane, which fell into the sea in America, corroded so rapidly that it emitted a clearly audible fizzing noise when standing in the shed after it had been salved.

Wing Commander Cave asked for further details of the Michel process if they were not secret.

He also asked whether magnesium occurred in nature in large quantities and in an easily accessible form, or was it like aluminium, which was present in large quantities but only comparatively rarely in accessible form.

His remarks were admittedly critical, but he did not wish to appear discouraging. The main fundamental fact was that magnesium had a density of 1.7 as compared with 2.7 for aluminium, and its physical properties were generally reasonable. For many rapidly moving parts, such as airscrew blades, this potential decrease in weight was of greater importance than a corresponding decrease in general structural parts.

Whether the great improvement, which was necessary to bring this material into general use, depended chiefly upon the metallurgist or on the manufacturer, he was not prepared to say. He considered, however, that great improvement was required, but that great effort was justified by the value of the prize.

Major BALL said: I have listened with great interest to the remarks of the last speaker. One of the first points to which he referred was the possibility of fire due to the properties of magnesium. Perhaps he had in mind the fact that during the war a powder was used for incendiary bombs which contained not only aluminium but also magnesium in a very finely divided state, which *did* burn furiously and was very hard to put out.

Fourteen years of research work on magnesium have led to the production in commercial quantities to-day of magnesium alloy castings and extrusions, and have shown that it is extremely difficult to set magnesium alloy on fire except in very finely divided form such as powder.

In Germany, and at Coventry, these castings are being turned out in very considerable quantities. In the foundries no fire of any kind has taken place, but in the machining of magnesium alloy at high speeds, where you get very finely divided dust, precautions have to be taken, as the dust will take fire easily. A small fire started under such conditions can at once be put out by smothering it with a mass of bigger turnings, or with dry or oil-soaked sand.

A second point was corrosion. The castings which went down in New York harbour were in sea water for 96 hours. They were brought back to this country and cut up. I had an opportunity of seeing them myself. Apart from the carburettor, the corrosion was not much more than aluminium would have shown in similar circumstances, and certainly not such as to have led to a "fizz." We have not yet overcome the corrosion difficulty in magnesium alloys so far as to put them on a par with all existing light metals, but through constant research we have made very distinct advances in magnesium bars and castings, which will give to-day results 50 to 60 per cent. better than bars and castings of a few years ago. The saving clause with magnesium alloys is that corrosion

is not inter-crystalline but surface, and there is the hope in our minds that the money which has been spent on these researches has not been spent in vain, and that a few months will show us a magnesium alloy with better anti-corrosive properties than aluminium.

The problem of corrosion is the biggest problem the manufacturers have to face, but it is being tackled, and by improvements in the alloy and not by external applications we hope shortly to produce an alloy in the electron series fit to take the place, for aircraft work, of any light alloy in the world.

In reply to a question: "Magnesium ribbon for photographic purposes is produced from finely divided particles and not made in the same way as magnesium alloy for foundry purposes. We can produce magnesium wire for electrical purposes which will stand the intense heat of high potential arcing without being ignited."

Mr. HANDFORTH said: Some of the audience might like to hear a few remarks by a user of magnesium castings. My first experience with magnesium alloys was rather amusing. It happened about two years ago, and one Saturday morning a magnesium alloy tensile test piece was sent along to me to test. I have forgotten what the ultimate strength of this particular test piece was, but out of curiosity I put one half of the tensile test piece into a beaker of water and left it there over the week-end. On the following Monday morning there was a heap of white stuff at the bottom of the beaker, but no test piece.

There have been other engines unfortunate enough to have fallen into the sea. With regard to one of them, it was said that there was no need to buoy the position of that engine as the water round it "boiled." In fairness to magnesium, I must state that very great improvements have been made in rendering it more resistant to corrosion. The earlier alloys that were supplied looked very good just as they were machined, but on standing they frequently developed black pit marks and corrosion continued until what had apparently been a good job, after a few days, became a pit-marked monstrosity.

Great improvement has been made in this direction, but unfortunately Mr. Jones has not indicated in his paper the method by which this improvement is obtained. He does mention the improvements brought about by freeing the metal from chlorides, but there is a further method of rendering magnesium more resistant to corrosion. Probably he will be able to tell you of that method.

In the paper considerable emphasis is laid on the properties of pure magnesium in constrast with those of other pure metals, but I think it ought to be pointed out in how very few cases engineers use pure metals as stressed members of construction.

Our iron is converted into steel, our copper into gunmetal, phosphor bronze or brass, and our aluminium into such alloys as L.5 or L.11, and it may be undoubtedly misleading to compare the properties of magnesium only with the properties of the other pure metals.

Another point, which was also emphasised by the first speaker, was that too much importance in the paper was attached to the terms mass strength and specific tenacity. I do not know quite how these terms strike other people, but to me they suggest a kind of juggling with figures.

Another point which has already been discussed is the risk of fire with magnesium. Certainly with the extra care which one would naturally give in the foundry, the risk of fire is not too serious, but as the last speaker said, the risk of fire in the machine shop has definitely to be considered. In our own machine shop we have three or four quite good conflagrations. The use of sand as an extinguisher is recommended by Mr. Jones, but it does not do a machine tool too much good to throw sand over it. I have found that the best method is the use of one of the foam type of fire extinguishers.

Somewhere in the paper it is stated that in order to remove chlorides from magnesium the molten metal is covered with ammonium chloride. I suggest that it must be singularly unpleasant to be in the neighbourhood whilst this operation is being carried out. The melting point of magnesium is given as 650°C., at which temperature ammonium chloride will volatilise very profusely.

With regard to the alloy elektron, the composition of this material must vary considerably. Elektron is given as a magnesium zinc alloy, but by far the greater portion of elektron I have handled has been a magnesium zinc aluminium alloy containing approximately 4½ per cent. of zinc and 3 per cent. of aluminium.

As a matter of general interest I might mention that castings made from this material give on the average 11—12 tons per square inch ultimate strength with 6—8 per cent. elongation. The best figures I have seen on such castings were 14½ tons ultimate with 11 per cent. elongation. For wrought alloys, such as extruded bars, I find that the alloy used is usually a magnesium aluminium alloy containing rather more than 10 per cent. of aluminium, and the test figures obtained from such material are in the neighbourhood of 18—20 tons ultimate with 2—7 per cent. elongation.

We are told that Anderson wrote, "There has never yet been made a truly sound aluminium casting." Possibly this is true, but if any medals were being awarded for bad castings, I think the producers of magnesium castings would not go short. For example, I have had submitted in perfectly good faith a magnesium alloy test bar which gave the figures 4.1 tons ultimate with 1 per cent. elongation. This, I suggest, is about as good as one might reasonably expect from a sample of brown paper.

With regard to the tensile tests I have quoted above and to the figures given in the paper, we ought to remember that these are test piece figures only. With a little experience and careful manipulation one can get very pretty results from test pieces. For example, it would not be very difficult to produce an L.5 test piece which gave 15 tons ultimate with 10 per cent. elongation, but how far these figures represent the strength of actual castings is a different story. I should also like to ask Mr. Jones if he has made any transverse tests on the wrought alloys. The figures given in the paper for extruded bars of magnesium alloy are said to be comparable with those of good quality wrought iron, but light alloys of this description suffer very badly from fibre and are very, very much weaker across the grain than along the grain.

The figures given in the paper for the zinc magnesium alloys are very interesting, but they would no doubt be more interesting if they were reliable. Surely, if they prove anything at all, they prove that the ultimate strength of the zinc magnesium alloys increase with the zinc content up to a maximum of 8 per cent. of zinc, but on page four and elsewhere in the paper the ultimate stress of the pure magnesium is shown as being greater than that of the alloys containing 4, 5 and 6 per cent. of zinc.

Finally, with regard to the use of magnesium alloys for pistons, possibly they are successful in certain cases, but they have very definite weakness for high duty pistons, the material is so soft (the Brinell hardness being not much more than 40) that the gudgeon pin bosses expand and crack unless they are steel lined, and frequently if they are steel lined the lining shakes loose in the boss. Possibly that is a difficulty which can be got over with more experience with these alloys, but up to the present I have not found them to be really satisfactory.

Mr. CHORLTON said: I quite agree with one or two things that have been said. With regard to the use of the metal in pistons, I have had some experience. In 1920 in Germany, when inquiring into the light metal position, I saw the electron people and was much interested in their metal. Later we made some experiments

and proceeded to forge it, as we thought we could make something of it in actual engines, etc. We made a number of pistons 8in. diameter, also a large aero engine connecting rod, but we found it very difficult to forge indeed. It needed 2,000 tons pressure. Though it was an extremely difficult metal to forge, this would no doubt have been overcome by experience. We put one of the pistons into service; ultimately it failed through the gudgeon pin boss. This was probably due to our not bearing sufficiently in mind the nature of the different metals. Had we continued we might have made a piston which would have been superior to the original. Castings for aero engine purposes are unsatisfactory and not to be recommended at all.

In regard to corrosion, we still have all the parts made lying about in the workshops, and they do not seem to have become any worse in three years. They have a peculiar external film of oxide which seems to effect the necessary protection. Work on this metal was stopped owing to such a limited demand and the cost of forging so high.

With reference to all metal aeroplane construction, no one has so far, this evening, raised the question of the rivet difficulty. The rivet is the critical factor in all metal machines. Heat treatment of them in narrow limits has a practical limitation.

As it looked as if magnesium would ultimately replace aluminium because of its lower specific gravity, I have asked, when in Germany, of its progress, but have been told that they could not get on because of being unable to produce satisfactory rivets. If anything has been done in the way of improvement during the last year, I should be very much interested to hear about it.

Mr. JESSUP said: I have been doing a good deal of work on magnesium in France and I should like to say a word or two about it. The supply of metal has been the subject of one question. There are very large supplies of raw material, of which magnesium carbonate is the most common, and there is any amount of it, more in fact than there is of bauxite, the raw material from which aluminium is manufactured.

*Incendiarism.*—I have recently been having a look at an all-metal Junkers machine at Geneva. It was stoutly built of very thick sheet metal, and I am certain that had it been built of magnesium sheet of equal thickness it could not possibly have been set alight, even if a flame had been played directly on it.

*Corrosion.*—The metal should be freed from chloride to begin with, and then alloyed with some special metal to lessen corrosion. Several remarkable tests have been made to show how free from corrosion magnesium alloys can now be made. I dipped some special alloy (nearly pure magnesium) in flux and left it for 15 months, and the metal was as uncorroded at the end as on the day it was made. Had water been present corrosion would have taken place, but salt without water does not have the same effect on these special alloys. I feel quite sure that researches going on in France will put magnesium from the corrosion standpoint very close to aluminium, and I believe we shall very soon see alloys comparable to the aluminium alloys. Abroad generally the corrosion problem, that is to say the saline corrosion problem, is not looked upon as it is in this country. Under ordinary atmospheric conditions magnesium does not corrode if free from chlorides. I have myself even seen some extruded bar which made the voyage across the Atlantic seven times (lying uncovered in the saloon of the vessel), and I can assure you there was not the slightest trace of incipient corrosion. At least one government with a large seaboard is contemplating manufacturing on a large scale.

The question of purifying the metal is however essential. I understand that results as to tensile strengths, etc., have been obtained considerably better than those quoted in the excellent paper we have heard to-night. This is probably

due to the fact that oxychlorides which form very fine and invisible inclusions have been got rid of. I myself did some experiments on German elektron which appeared to be free from chloride inclusions. I alloyed this metal with some 10 per cent. Ca alloy, both of which had been chemically tested with the utmost care for chlorides and found to give results showing chlorine as less than 0.002 per cent. in each case as apart from oxychlorides, while the resulting alloy showed large chloride inclusions, which were confirmed by analysis. This is almost certainly due to reduction of the invisible and non-hygroscopic magnesium oxychloride by the molten calcium. These higher figures are therefore probably due to the fact that recent methods have succeeded in eliminating these very fine oxychloride inclusions as well as the grosser inclusions which cause more obvious flux marks.

Mr. A. E. PARNACOTT inquired as to the bearing metal properties of the pure magnesium in view of the fact that pistons function as bearings when rubbing on cylinder walls.

Mr. SUTTON: In the first place I should like to ask if Mr. Jones would give us a few details on the extensive application of "elektron" in aircraft in Germany to which he refers in his paper.

I should like to ask the author if he has himself tested out the process for producing coatings of hydroxide or oxide of the metal by heating in steam under high pressure, a method first described by G. Backer some years ago. The possibility of improving the low resistance of the metal to corrosion by sea water in this way is of interest.

The abnormally low modulus of elasticity and very low proof stress of the magnesium metal and alloys are important features. I mention this because a good many failures have occurred in the application of the metal and alloys in practice, consequent upon the omission of consideration of these factors.

Another property of interest in practical considerations is the high coefficient of expansion which has caused trouble in the use of pistons in magnesium alloys. The troubles in piston work are probably due to the fact that the thermal characteristics of engines differ appreciably and that for each engine there are optimum clearances for magnesium alloy pistons. Owing to the high thermal expansibility of magnesium alloys, higher than that of the usual aluminium alloys used for pistons, the clearances need to be determined with precision.

Mr. W. O. MANNING: I should like to congratulate Mr. Jones on putting before us in such an able manner the facts about magnesium.

This metal is peculiarly interesting from an aeronautical point of view as it possesses the least specific gravity of any metal likely to be available for structural purposes and it is therefore of great importance that research should be carried out on its properties and also on the properties of its alloys.

Such an investigation holds out possibilities of a reduction in the structure weight of aircraft, a matter of vital importance.

I think that it is clear that this metal is still in its infancy as regards its commercial applications, but I am sure that this paper and this discussion have clarified the difficulties and will make further progress much easier.

There is only one point I should like to refer to and that is the very low figure obtained for the Izod and Charpy tests, such a low test suggests serious danger of fracture owing to tool marks, slight dents, scratches, etc., in parts subjected to stress, and I think that the material cannot be considered as safe for stressed parts until more reasonable notched bar figures can be obtained.

Mr. L. P. SIDNEY (*contributed*): Mr. Jones' paper is a most practical contribution to the literature of a subject which, despite the valuable work of Dr. Aitchison and of Mr. Archbutt, is still insufficiently appreciated by British engineers.

It was interesting to note that Mr. Jones had found no difficulty in forging commercially pure magnesium. It was a metal which as a rule did not behave well under sustained pressure, although curiously enough it extruded well. The figures given for the tensile strength of the maxium metal seemed rather low. A commercially pure sample tested at the Conservatoire des Arts et Mètiers, Paris, some months ago gave 17 tons per sq. in., extruded bar, and the calcium containing metal gave even higher results. The calcium is, however, difficult to eliminate. Had Mr. Jones tested his samples for chlorine, which was a not uncommon contamination in samples of what were described as commercially pure magnesium? The double fusion process employed at the National Physical Laboratory in getting absolutely sound aluminium castings was applicable to magnesium, but a very high head would be required. Could Mr. Jones give any information as to the head he employed when making castings?

Commercially pure magnesium tarnished somewhat readily under normal room conditions, but the matt film that formed was protective and very little real corrosion occurred afterwards, although if too much zinc was present, or any of the chlorine contamination referred to above, a certain degree of pitting occurred. Fairly effective protection was afforded by certain organic solutions of the phenol class and it was probable that some form of plating could eventually be devised for the ultra light metals which would render them more generally serviceable in the unfavourable conditions which obtained in seaplane engineering. The presence of zinc was undoubtedly conducive to corrosion, and the elektron series of magnesium alloys were prone to corrosion in not very severe atmospheric conditions.

As Mr. Jones pointed out, the fire danger was greatly overrated in the case of magnesium alloys. Magnesium wire, when ignited, as often as not failed to continue burning and went out spontaneously owing to the high heat conductivity of the metal which reduced the temperature at the point of ignition and cooled the metal below combustion point. Such wire had a peculiar fibrous structure often characteristic of the metal when worked in a special manner and with careful heat-nursing. That structure, imparted to pistons of maxium metal in the process of their manufacture, had an important bearing on the question of piston design. The metal, owing to its heat evacuation properties, could be used liberally; it was not necessary to make the pistons light at the expense of the mass required to secure a proper margin of strength. That was a practical consideration which should appeal to engine makers for auto and aeronautical purposes.

In practice magnesium pistons were apt to slap a bit before warming up, but so did aluminium pistons. On the other hand, they did not seize when warm, as was alleged to occur in the case of aluminium. He (Mr. Sidney) understood that duralumin pistons were free from both defects. There was ample room and unlimited applications for both metals and for other alloys and the sooner the possibilities of magnesium were recognised the sooner the demand would result in a further cheapening of the metal.

Mr. W. R. D. Jones, in his reply, said: The discussion has been of great use to me. I can recommend those gentlemen who spoke about all-metal aircraft to a paper given by de Woitine to the Institution of Aeronautical Engineers a year ago. He goes into the subject very fully and solves quite a number of the questions you asked.

Two gentlemen asked about machining the metal. Both the unalloyed and alloyed metal is exceedingly easy to machine. Very high speeds can be used, limited only by the diameter of the bar. It machines much better than aluminium. We have machined 10 per cent. copper alloy and the pure metal and find no appreciable difference in machinability.

About conflagrations likely to take place in the machine shop. The fine dust due to machining means that precautions must be taken, but if a boy cleans up at the end of each shift there ought to be no difficulty. We have our shop cleaned up straight away. If a fire happens the best thing to use is a cold slab of iron.

Magnesium is not a thoroughly well-known metal yet. There is a very large amount of work to be done on it. The problem of corrosion is being tackled and there is very much less of it now than two or three years ago. We are testing pieces for corrosion in our laboratory. Of course a great deal depends on the crude material. One bar sent me soon developed intense pitting on testing. With good metal kept free from impurities corrosion problems are greatly minimised.

The question of using pure metals. They are being used to-day much more than is generally imagined. Large diameter water pipes are being made of pure iron, copper in tubes is almost pure, nickel is a metal that is becoming very important by itself, apart from its alloys, etc.

*Forging.*—Magnesium, provided it is forged at the right temperature, will withstand brutal treatment. It can be hit as hard as ever it is needed. A bar after being forged down will ring well. It does, however, require a rather large amount of power.

I am very much interested to know that elektron sheets are being successfully riveted with duralumin. Of course galvanic action would not be nearly so intense as if you had elektron and iron or copper rivets.

*Chloride Inclusion.*—I am quite in agreement with the speaker on this point. We have been able to get rid of it without the use of calcium, which is apt to have an embrittling effect if more than mere traces are left in the bar, and obtained very good sound bars free from any defects at all.

*Pistons.*—One could talk about pistons for about three hours. One of the mistakes has been to try to make magnesium pistons the same design as if they were of cast iron. You must alter your design when using a new metal. It is necessary to get your piston as solid as possible and avoid porosity. You can more than double the cross section if magnesium is used and then obtain a lighter piston than one of similar design in cast iron.

*Aluminium Pistons and their Growth.*—Dr. Aitchison has given a very fine account of aluminium pistons. Growth can be done away with if you give them a preliminary heat treatment above the working temperature.

I have no definite personal knowledge of the extent to which elektron is used in Germany, but I understand that it is used for trolley wheels of electric cars, and is marketed in the form of castings, bars, shapes, tubes, wire, drop-forgings, sheets, etc.

We have started corrosion tests at our laboratory, but we had no details ready for this paper. However, we are pretty confident that the alloys are not nearly so readily corroded as the pure metal.

Magnesium is a new metal which I am convinced will play a very important part in the future. It has certain obvious advantages, and proper forging will eliminate many of the defects which have been found in it.

Large tool marks should not be left on a test piece or any machined article. Test pieces, for strictly comparative results, should be ground finished.

I am very grateful to all those who have joined in the discussion. It is of great advantage to hear the opinions of practical men.

In reply to Colonel the Master of Sempill, it has been found that these alloys are more readily machined than aluminium alloys, many of which are liable to

drag. The tool should be given a fair amount of lip. The question of corrosion due to sea water is necessarily very important and is being investigated. Magnesium and its alloys are admittedly more readily attacked by sea water than aluminium and its alloys. The deterioration of present day magnesium by the usual atmospheric agencies is not to be feared and it compares very satisfactorily with the majority of other commercial metals. The corrosion of aluminium and its alloys is certainly decreased by the anodic oxidation process described by Bengough and Sutton.[18] As far as the author can ascertain, no experiments on magnesium and its alloys have been carried out on these lines. The resistance of magnesium and its alloys to corrosion is due undoubtedly to the presence of a protecting film of oxide or hydroxide. Consequently, if a thick adherent film of oxide is formed on these materials corrosion would be decreased. This could probably be accomplished on the lines evolved by Bengough and Sutton. Mention was made in this paper[19] of a method used to increase the thickness of the oxide film on magnesium wire. There seems to be no apparent reason why this method cannot be adapted for general use with these alloys. Further, it is fairly certain that the process would be satisfactory for electrical purposes because a coating of 0.1 mm. thickness will not break down under a voltage of 220.

Wing Commander T. R. Cave-Browne-Cave criticises the terms "specific tenacity" and "mass/strength ratios." These units, which are merely ratios of tenacity with density, are more readily appreciated than the unit which he recommends, viz., that of a length expressed in metres which, hanging free, would just break from its own weight—this does require a little imagination! Colonel C. Grad in his book, *Aluminium and its Alloys* (1921), states that several parts of the Zeppelin L.49, brought down at Bounboune, were made from magnesium rich alloys of the elektron type. Magnesium is about the eighth most abundantly occurring metal. The chloride is a constituent of sea water and the famous Stassfurt deposits are rich in this salt. Carnalite is one of the minerals from which most of the metal is at present manufactured. Dolomite is another abundantly occurring mineral containing a large amount of magnesium carbonate, which is a potential source of the metal.

Mr. Handforth's remarks are interesting in that though he is very sceptical of the usefulness of these alloys, he admits that magnesium has improved greatly of recent years. Elektron is a loosely applied term for an alloy of magnesium which contains zinc as the predominating alloying metal. Generally elektron contains small quantities of other metals such as aluminium, copper, iron, manganese, etc. Consequently test data of various samples of this alloy are not strictly comparable. Mechanical testing has been developed in order to keep control of the quality of various metallic parts, by a correlation between tests carried out in the laboratory in a short time with those under actual working conditions—a necessarily long period of time. The real test of a casting or a structural member is that of its behaviour in use. What is the advantage of a manipulation of test figures other than a pecuniary one? The figures quoted in the paper are reliable and are to be taken as minimum values; those from the author and his colleagues' work on the copper magnesium alloys are the average of many concordant results. Although castings are generally weaker across than along the grain, the effect of grain decreases considerably on correct forging. Further, it does not necessarily follow that immediately on the addition of an alloying element the tensile strength increases. In some of the figures given, *e.g.*, the zinc magnesium and the aluminium magnesium alloys, the tensile strength does not at once increase. This will account for the fact that the magnesium itself gives better results than the 4 per cent. zinc alloy and the 4 per cent. aluminium alloy in the cast condition. It is to be hoped that Mr. Handforth's

[18] Section G (Engineering) of the British Association for the Advancement of Science, 1926.
[19] Page 19.

experience in the future will prove as good as those of many now using magnesium and its alloys without trouble.

In reply to Mr. Parnacott, who asks for information on pistons, Dr. Aitchison gives an excellent treatise on the use of aluminium and of magnesium and their alloys in a paper to the Institution of Automobile Engineers in 1924. He states "if a proper discrimination is to be exercised in the choice of an alloy, the properties to be looked for in a good alloy should be clearly understood. The following schedule gives those particular attributes that may conveniently form the basis of a true comparison:—

1. Mechanical properties at the ordinary temperature.
2. Mechanical properties at elevated temperatures.
3. Machinability.
4. Permanence.
5. Ease of production in a sound state.
6. Thermal conductivity.
7. Thermal expansion and contraction.
8. Cost.
9. Specific gravity.
10. Melting range.
11. Facility of running in a cylinder.
12. Hardness to resist wear on skirts and loads."

It is necessary, especially in the case of pistons for use in aeroplane engines, that there should be complete absence of porosity which always tends to lead to erosion on account of the hot gases being continually forced through. Cast iron, which has been used extensively as a piston material, suffers in comparison with magnesium (and aluminium) on account of its low thermal conductivity, low tenacity and high specific gravity. The success of light alloy pistons is due largely to their comparatively high thermal conductivity. The design of a piston should be modified according to the coefficient of heat conductivity of the metal used. Metal of low conductivity would require to be much thicker in cross section than a metal of high conductivity in order to secure the same degree of cooling in the piston.[20] It is in connection with this point particularly that the use of magnesium and its alloys is advantageous. They are light and of high conductivity so that the wall thickness may be relatively large. A piston head cool under working conditions has many obvious advantages, not the least of which is a gain in efficiency not only through the cooling itself, but owing to the greater volume of the less expanded gas on admission due to the cooler walls and freedom from carbonisation due to the breakdown of the oils caused by hot working conditions.

The author is grateful to Mr. L. P. Sidney for his valuable contribution to the paper. It was not considered necessary at the time to test the raw material for chlorine, owing to its high degree of purity. No figures are at present available as to the head of metal used in casting except that a much higher head is necessary in casting magnesium than for aluminium owing to the difference in density.

[20] "Engineering," July 30th, 1926. "The Pistons of Internal Combustion Engines."

# RESUMÉ OF TECHNICAL INFORMATION

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## AIRCRAFT

### *France*

*Tests of the Bleriot 127.*

*Les Ailes*, 20th August, 1926, No. 270. (1926)

The Bleriot multi-seater fighter monoplane, type 127, is now being tested by the S.T.Ae. at Villacoublay. The monoplane, which has two 450 h.p. Hispano-Suiza engines, broad arrow type, climbed at 23,600ft. in 42 minutes.

The speed over the measured base is 137 m.p.h., 131 m.p.h. at 16,400ft. and 128 m.p.h. at 19,700ft.

These results were obtained after the machine had been carefully trued up. Bissoutrot was the test pilot.

### *Holland*

*New Fokker Seaplane.*

*Les Ailes*, 12th August, 1926, No. 269. (2926)

It is reported that Fokker is designing a very strange seaplane. It consists of a wing having a very pronounced sweep back and a considerable dihedral. The machine has neither body nor tail, but will rest on the centre underpart of the wing, which is considerably bulged out at this point. It is to be fitted with an engine developing 150-200 h.p.

### *U.S.A.*

*On the Proposed Trans-Atlantic Flight. Curtiss Falcon Plane Revised.*

*Aviation*, 23rd August, 1926. (3926)

*Aviation*, 6th September, 1926. (4926)

The all-metal airplane to be used is being built by the Sikorsky Aero Engineering Corporation and represents the result of Igor Sikorsky's eighteen years' experience in the design and construction of airplanes, mostly of the larger types. The plane was designed as a passenger and freight carrier, equipped with three Gnome-Rhone-Jupiter engines of French manufacture. These engines develop 420 h.p. each, driving tractor propellers. The plane was originally described in *Aviation*, May 31st.

The pilot's cockpit is equipped with dual controls. It is entirely enclosed, but sliding windows are located at the top and sides. A door at the rear of the pilot's cockpit leads to the cabin, which has a 450 cub. ft. space for cargo or for seating twelve passengers in comfort. The cabin is 4ft. wide, 6ft. high and 15½ft. long. Two doors at the front of the cabin lead to the lower wing, so that during flight mechanics may reach the two engines, carried in streamlined nacelles, if they should require adjustment. At the rear of the cabin, one door is located at the left side for entrance while the plane is on the ground, while another door at the rear leads to the lavatory. Sliding non-shatterable glass windows 18in. by 24in. are arranged along the cabin, which is finished in mahogany, fitted with electric ceiling lights, ventilators and heaters.

Radio equipment for transmitting on regular waves and short waves will be used during the flight in an endeavour to keep in communication with surface ships and land stations. In addition to the radio, weighing 160lbs., other equipment to be used especially for the flight will weigh 330 lbs.

Owing to the use of self-compensating rudders it is possible to fly the plane on any of the three possible combinations of two engines without affecting the ease of control. The all-metal feature is another of the outstanding points of design. The entire framework of the body is composed of duralumin channels, tubes and plates, assembled with steel bolts and rivets. No welding is used throughout the entire structure. There are no wires or structural members crossing the cabin space, and the cabin is braced with diagonal channel members, resulting in a particularly rigid body in which vibration is not apparent. Fabric is used for the outside covering.

The wing structure, which is made up entirely of duralumin, is the most advanced type of construction. Beams are built up to I-section formed by means of four duralumin angles riveted to the central web of flat sheet duralumin. The ribs are formed of light sheet duralumin channels and angles. In plan form the wing tips taper to a knife edge. High tensile strength tie-rods are used in the internal drift bracing system.

Ailerons, hinged on auxiliary beams aft of the main wing beams, taper at the tips and mortise into the wing. The tail surfaces built like the wings are fabric covered. The stabiliser is adjustable and may be used without difficulty during flight to compensate for any disturbance of the fore-and-aft balance of the plane, or for varying the attitude of the machine for slow landing.

The landing gear is of the divided axle type, made entirely of steel, with parts bolted together. No welding is used on any part. The wheel tread is exceptionally wide, being 18ft. 4in.

The general details of the machine are as follows:—

Span, upper wing, 101ft.
Span, lower wing, 76ft.
Height, 16ft.
Total wing area, 1,095 sq. ft.
Weight empty, 8,000 lbs.
Loading per h.p., 19 lbs.
Loading per sq. ft. of wing area, 21.85 lbs.
Crew of three (two pilots and one navigator), 510 lbs.
Special equipment, 590 lbs.
Total weight of fuel and oil, 15,200 lbs.
Total weight of machine, 24,200 lbs.

Fuel for the wing engines is carried in the rear part of the engine nacelles in streamlined tanks.

The Curtiss Aeroplane and Motor Co. has recently delivered a revised O-1 Falcon observation airplane to the Army Air Corps, and the airplane is now at McCook Field undergoing test. The Falcon was described in the issue of *Aviation* of July 19th.

In the revised machine the observer's cockpit has been made considerably deeper, thus protecting the observer from the slipstream and increasing the accuracy of his gunnery. The underslung fuel tank, formerly used as an auxiliary, has been made permanent, and faired so as to carry out the lines of the deeper fuselage. It is interesting to note that, in spite of this increased depth, the lines have been so carefully worked out that the high speed of the machine has actually been increased.

Another improvement consists of changes in the cowling and wind-shield for the observer's cockpit, resulting in greatly improved vision and making the Falcon much easier to fly from the rear seat than other observation types.

Other changes include a re-design of the rear seat to accommodate either seat or lap-type parachute, addition of a large luggage compartment, installation of mechanic's steps on the engine mounting, and minor changes in the location of instruments and accessories.

All of these changes have been made as a result of the recommendations of Air Corps personnel, who have been flying the first consignment of Falcons during the past few months. From present indications the revised machine will further enhance the popularity of the Falcon type, which has been steadily gaining favour with the flying personnel of the Air Corps.

## Power Units and Fuels

### *The Wright-Morehouse 25-30 h.p. Airplane Engine.*

*Aviation,* 23rd August, 1926. (5926)

The Wright-Morehouse light plane engine is a two-cylinder horizontally opposed, four-stroke cycle, air-cooled engine. It has a cylinder displacement of 80 cub. in. to fit in with the classification for light plane engines employed by the National Aeronautic Association and foreign sport-governing bodies. With this displacement the engine develops 29 h.p. at the normal speed of 2,500 r.p.m. At this speed the brake mean effective pressure is 114 lbs. per sq. in. The fuel consumption at normal speed is only 2.5 gallons per hour at full throttle, a very fine performance for an engine of this size.

Bore, 3.75in.
Stroke, 3.625in.
Displacement (1.31 litres), 80 cub. in.
Compression ratio, 5 : 1.
Rotation anticlockwise.
Weight (dry), 89.5 lbs.
Power at 2,500 r.p.m. (average), 29 h.p.; guaranteed, 25 h.p.
Fuel consumption at 2,500 r.p.m. (average), 2.5 gal./hr.; guaranteed, 0.55 lb./h.p.-hr.
Shipping weight, 155 lbs.

### *Anti-Detonation Piston.*

*Le Genie Civil,* June, 1926, page 570 (France). (6926)

Dumanois has designed a piston which is said to effect a considerable increase in the highest compression ratio which can be employed without knocking. The special features of the piston are that it has four steps of a height of 3½ m/m. and a width of 16 m/m., and that the spark plug is located laterally on the side of the highest step. With this piston it was found possible to increase the compression ratio of the engine to 6 : 7 without detonation occurring.

### *Cracking Process for Production of Non-detonating Fuel.*

*Journal of the Society of Auto-motive Engineers,* July, 1926 (America). (7926)

It has been shown that fuels produced by certain cracking processes are appreciably better, from a detonation standpoint, than uncracked fuels, and that they should have a compression limit of about 85-90 lbs. per square inch.

### *Gas Fuel for Airships.*

*Les Ailes,* 1st July, 1926 (France). (8926)

It is stated that the new airship L.Z.127 is to be fitted with five special Maybach engines, using as a fuel a gas of about the same density as air. The advantage of such a fuel is stated to be that it will no longer be necessary to lighten the airship by wasting large quantities of hydrogen to compensate for the loss in weight resulting from the decrease in petrol carried.

*Superchargers.*

*N.A.C.A. Report* No. 230. (9926)

Laboratory tests of a Roots supercharger for aero engines are described in *N.A.C.A. Report* No. 230.

## MATERIALS

*Aluminium-Silicon Casting Alloys.*

*Trans. Amer. Inst. Min. & Met. Engrs.*, February, 1926 (America). (10926)

Much research activity prevails in several countries in the study of the modified process of aluminium-silicon casting alloys. The effect of silicon and iron content on the mechanical properties of sand casting has been investigated.

*Beryllium.*

*Les Ailes*, 6th May, 1926 (France). (11926)

German work on beryllium is described in *Berichte Deut. Chem. Ges.*, 1925, Vol. 58 (2), p. 1,571, *Les Ailes*, 6th May, 1926.

It is stated that this metal is shortly to be put on the market; the density is stated to be 1.8 and the tensile strength to be 40 kg./sq. m/m.

## AERODYNAMICS

*Variable Density Wind Tunnel.*

*N.A.C.A. Report No.* 221. (12926)

A systematic series of 27 wing sections have been investigated at twenty atmospheres pressure in the variable density wind tunnel of the National Advisory Committee for Aeronautics. The results are given in *N.A.C.A. Report No.* 221.

*Rotating Cylinder in Wing Section.*

*Report of the Aerodynamics Institute, Amsterdam* (Holland). (13926)

The results of some experiments on the combination of rotating cylinder and a wing section are given in Report No. A.96 of the Aerodynamics Institute, Amsterdam.

## MISCELLANEOUS

*Night Errors in Radio Direction Finding.*

*Journal of the Institute of Electrical Engineers*, August, 1926. (14926)

An important paper on the elimination of night errors appears in the *Journal of the Institute of Electrical Engineers*, August, 1926. By the use of the special aerial system described, observations from an aircraft showed bearing errors of $-1°$ to $-6°$ compared with errors of from $+40°$ to $-23°$ with an ordinary revolving loop aerial.

*Danger of Fire to Airships from Electrical Discharges.*

*Zeitschrift Fur Techn. Phys.*, 7, 238-239, 1926, No. 5 (German). (15926)

Investigations on this subject are described in the above journal.

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# REVIEWS

## *Aircraft and Commerce in War*

By J. M. Spaight. (Longmans, 6/-.)

Having dealt exhaustively in a former volume, *Air Power and War Rights*, with the laws of aircraft in warfare, Mr. Spaight has taken a branch of the subject and elaborated it in his new book. There is no doubt that one of the most important subjects for consideration at the Air Force Staff College, and the newly-formed Imperial Staff College, will be the uses of aircraft in the economic campaign, which will be one of the most important aspects of all future wars. It is a subject which bristles with difficulties, as it is not merely a question of the best utilisation of the weapon of attrition against an enemy, and the best defences against its use by him, but raises wide political questions of expediency if neutrals are not to be driven into the arms of the other side—as Germany learnt to her cost in the case of America in the last war.

Mr. Spaight's main thesis of the importance of concluding agreements in time of peace with the traders of nations likely to be neutral in the event of an outbreak of hostilities, has been the subject of an interesting correspondence in the *Times Literary Supplement*, in which the difficulty of arranging these in the absence of a treaty between the Governments concerned was pointed out. There are, of course, precedents from the policy pursued by our Government during the Great War, but it is difficult to see how similar arrangements could be negotiated until a state of war existed, when they must depend upon a certain benevolence on the part of the government of the neutral state, carefully cultivated by the diplomat. Not the least obstacle to any prior attempts on the part of our Government to lay the groundwork in times of peace is that this country is more vulnerable than others to the economic method of attack—which is why we must resist any tendency to limit belligerent rights in regard to contraband and blockade, or the use of aircraft in connection with them.

Mr. Spaight draws attention to the fact, which must be faced, that if used as they will be for attack on enemy, and even neutral, merchant ships on the high seas, aircraft will inevitably introduce even more ruthless methods into maritime war than the submarine, for they will be unable to exercise the right of search and will hardly be able to give the customary merciful warning to the crews to take to their boats. As he says, these facts "may be regrettable and terrible, but if they are probable they should be faced," although "that such attacks will be entirely illegal is certain." Such methods will not, of course, be used at the beginning of a war, but may be expected when one of the belligerents is beginning to feel the effects of a prolonged war of attrition, and have a precedent in the "unrestricted" submarine warfare introduced by Germany in 1917. Up to the present the question of the rights and limits of aircraft in operations against merchant shipping has been rather shied at by jurists on account of its complexity; but the claim for them to have power to order a merchantman to deviate from its course for search, and to enforce that order by bombs or torpedo as well as machine-gun attack, seems to depend upon such logicality that it is difficult to see how it can fail to carry ultimate acceptance.

Mr. Spaight has raised interesting questions in this book and provided much food for thought, as well for the strategist as for the jurist. It is admirably documented with references and notes, as one has come to expect from him.

### *The Book of the Aeroplane*

By Captain J. Laurence Pritchard. (Longmans, 7/6.)

The Society has been fortunate in having a succession of Secretaries with a taste for writing, of whom not the least gifted is the present holder of that office. He has followed in the steps of a predecessor in producing a popular book on the aeroplane for the benefit of the general reader, and his essay in this direction inevitably provokes comparison with *The Boy's Book of Aeroplanes,* published in 1912 by Wing Commander Hubbard, in conjunction with Major C. C. Turner, who has through his articles in the Press over a long period done more than any other single individual to instruct the public in the elements of aeronautics. Captain Pritchard's book of necessity covers a much wider field than the earlier work, and in consequence suffers somewhat by comparison in regard to the historical portion, partly as the result of enforced compression. This has led him in some cases to make claims for the early students of the subject that can hardly be substantiated. There is, for instance, no evidence that Leonardo da Vinci ever built the parachute of which he gives a small sketch in the Codex Atlanticus, nor reason to believe that his seventeenth century successor Veranzio was any more enterprising—still less that " he made a number of successful jumps from heights." There is, in fact, little doubt that the parachute remained purely an idea until put to practical trial by Lenormand in 1783. The author is in fact a little too prone to dismiss the experiments of the early workers with the statement that they were " successful "—an assertion which is, to say the least, challengeable in the case of Leonardo da Vinci, Guidotte and Robert Hooke. He has, one believes, misunderstood the principle of W. H. Phillips's 1842 helicopter, the " fans " of which were not turned by the impinging of steam on the blades, as he states, but by the repulsion effect of jets of steam emitted from the rear edges of the extremities of the fans themselves. He also exaggerates Ader's claim to having flown in 1897, by giving as the length of the " flight " the total distance of 1,000 yards covered during the whole run of the " Avion " from the starting-point to the final crash. Ader himself never claimed to have covered more than 300 yards in flight, and even that is, of course, highly debatable. In dealing with the work of the Wright brothers, Captain Pritchard erroneously states that in the 1905 machine the pilot occupied a prone position on the lower plane, whereas actually this was a feature of the 1903 machine only, a seat being fitted in the 1904 and all subsequent Wright machines. The brief reference to Stringfellow's experiments might have been extended to mention that, though it is true, as stated, that his 1848 model crashed on its first test, it subsequently made a number of completely successful flights after adjustments to the tail setting, and was in fact the first model aeroplane to fly. Finally, to have done with cavilling, the Aerial Derby never was other than a scratch race, though a handicap race was run concurrently with the main contest in the later years.

The author succeeds in covering in an interesting manner the whole field of aeroplane activity, giving a clear popular account of " How an aeroplane flies "—by no means an easy thing to do—and in Chapter VII. an excellent description of the elaborate ground organisation required to maintain the " Great Airways of the World " described in the previous chapter. The book is concluded with a glimpse into the future, in which, for one who is an experienced imaginative writer, a commendable restraint is shown; but it is interesting to see that Mr. Kipling's forecast of the apportionment of different levels to machines of varying types and speeds is adopted, a scheme which has hitherto been rejected by the International Commission despite the warm advocacy of Lord Montague of Beaulieu and others. A book that may be recommended as a foundation on which to base further reading, which is the avowed object of its production, and serving as an excellent introduction to the study of aviation.

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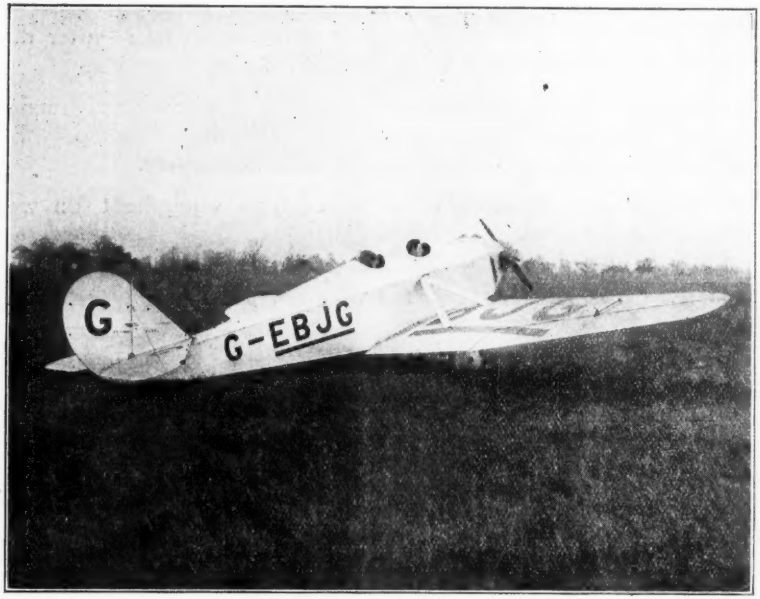


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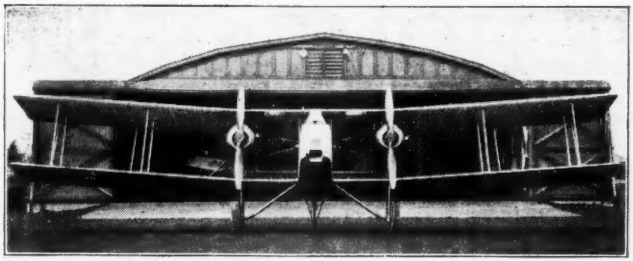

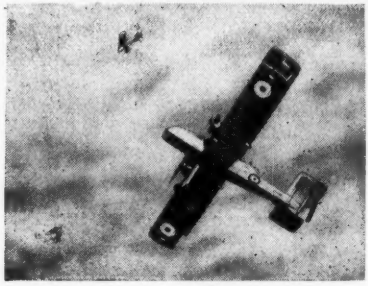

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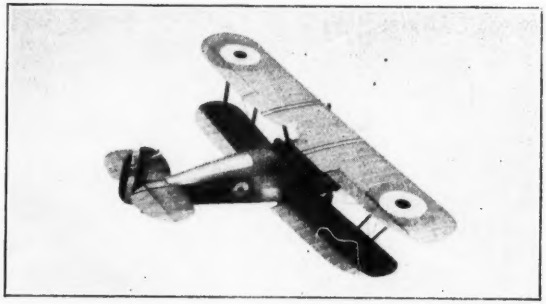

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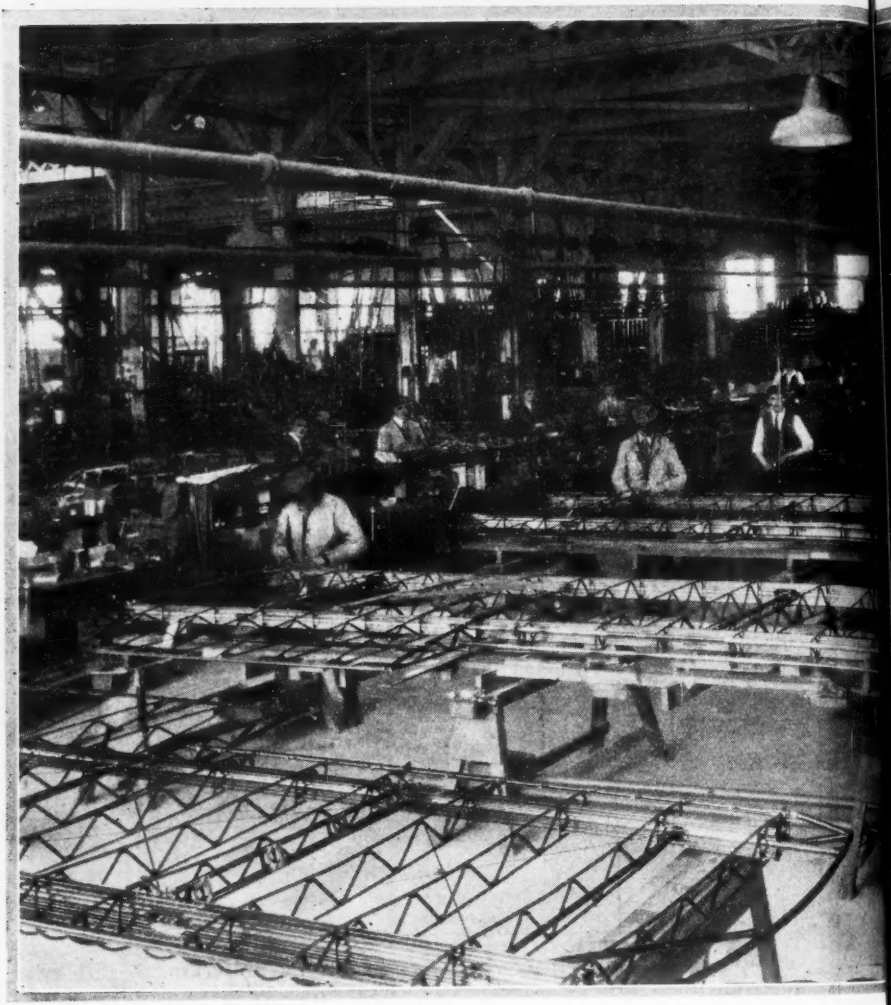

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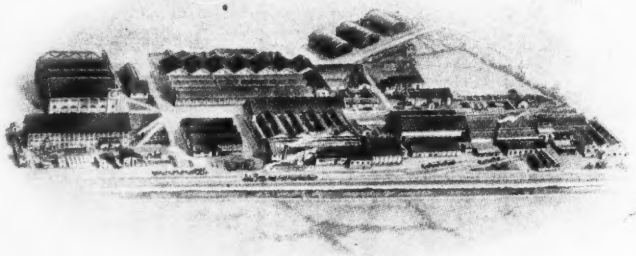

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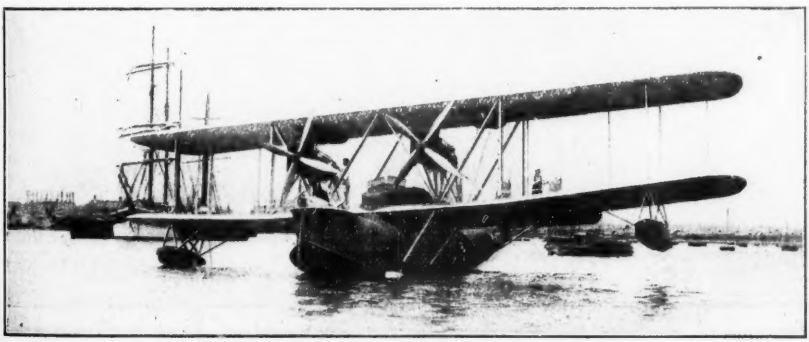

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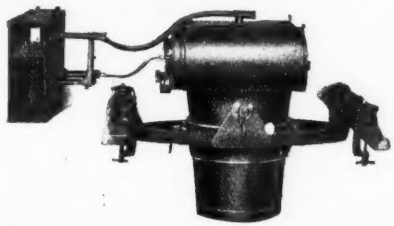

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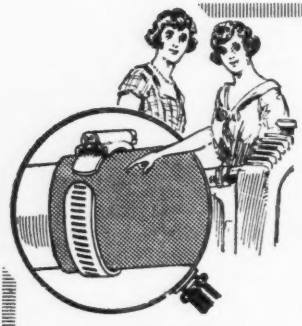

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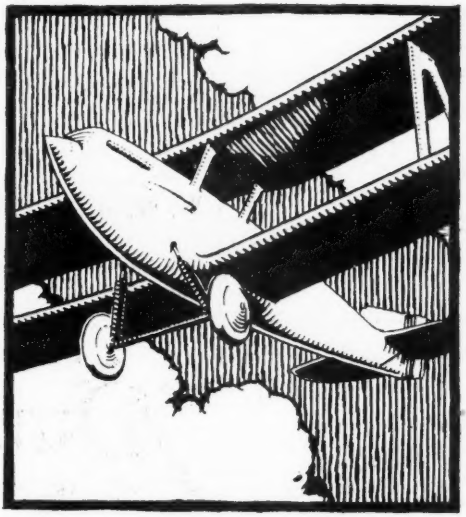

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Information concerning surveys and the cost of such work may be obtained from the Secretary:—

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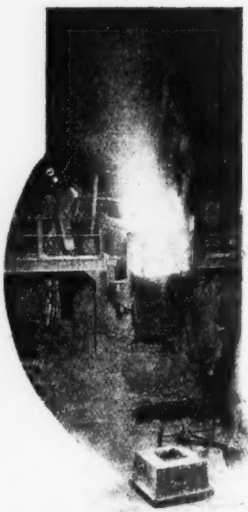

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